NorthMet Project

Adaptive Water Management Plan

Version 2

Issue Date: July 10, 2012

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1.0 Introduction

This document describes the Adaptive Water Management Plan (AWMP) for the NorthMet Project (Project) and presents the adaptive engineering control designs that manage water quality impacts. The expected water quality at SDEIS evaluation points, the water quality and quantity monitoring plans and reporting requirements are described in Water Management Plan – Mine (Reference (1)) and Water Management Plan – Plant (Reference (2)) which are integral parts of this document.

The Project includes engineering controls to manage the environmental impacts. Some engineering controls are fixed and some are adaptive. The fixed engineering controls are described in the Water Management Plan – Mine (Reference (1)), Water Management Plan – Plant (Reference (2)), Mine Plan (Reference (3)), Rock and Overburden Management Plan (Reference (4)), Flotation Tailings Management Plan (Reference (5)) and Residue Management Plan (Reference (6)) (collectively referred to as Management Plans). The adaptive engineering controls are described in this document.

The AWMP and the Management Plans are components of the Minnesota Department of Natural Resources (MDNR) Permit to Mine and Minnesota Pollution Control Agency (MPCA) National Pollutant Discharge Elimination System (NPDES) / State Disposal System (SDS) Permit and are interrelated. Table 1-1 shows that interrelationship by showing the cross references between the AWMP and facility Management Plans. The Project Description, AWMP and Management Plans are the Proposed Project evaluated in the SDEIS.

Any references to current model results refer to the model results with the engineering controls implemented as described in this document. Any references to current design refer to the designs as described in this document.

Several acronyms are used in this document including Mine Site Waste Water Treatment Facility (WWTF), Flotation Tailings Basin (FTB), and Tailings Basin Water Treatment Plant (WWTP)

1.1 Objective and Overview

The objectives of the AWMP are to

- describe a system for managing the implementation of engineering controls to mitigate Project impacts to water quality in a manner that results in compliance with applicable surface water and groundwater quality standards at appropriate evaluation points as estimated by modeling and demonstrated by monitoring, and

- disclose the assumed performance parameters for adaptive engineering controls used in modeling and changes to modeling parameters as a result of the application of those controls.

1.2 Outline

The outline of this document is:

Section 1.0	Overview and outline
Section 2.0	Description of Category 1 Waste Rock Stockpile Cover System including key factors driving the design, initial design, potential modified designs and circumstances that would trigger a design change.
Section 3.0	Description of Category 1 Waste Rock Stockpile Groundwater Containment System Extension including key factors driving the design, initial design, potential modified designs and circumstances that would trigger a design change.
Section 4.0	Description of Category 1 Waste Rock Stockpile Groundwater Containment Passive Treatment System including key factors driving the design, initial design, potential modified designs and circumstances that would trigger a design change.
Section 5.0	Description of Additional WWTF Antimony Treatment in Closure including key factors driving the design, initial design, potential modified designs and circumstances that would trigger a design change.
Section 6.0	Description of West Pit Overflow Passive Treatment including key factors driving the design, initial design, potential modified designs and circumstances that would trigger a design change.
Section 7.0	Description of FTB Water Management including key factors driving the design, initial design, potential modified designs and circumstances that would trigger a design change.
Section 8.0	Description of FTB Cell 1E/2E Enhanced Cover System including key factors driving the design, initial design, potential modified designs and circumstances that would trigger a design change.
Section 9.0	Description of FTB Passive Treatment including key factors driving the design, initial design, potential modified designs and circumstances that would trigger a design change.

Because this document is intended to evolve through the environmental review, permitting (SDS, Water Appropriations and Permit to Mine), operating and closure phases of the Project, some design details will not be provided until future versions of this document. This document will be reviewed and updated as necessary through the environmental review and permitting process in conjunction with changes that occur and for future permitting needs. A Revision History is included at the end of the document and the most recently updated sections are highlighted in gray.

1.3 Definitions

The following definitions apply in the context of this document and are illustrated in Figure 1-1.

Proposed Project: Consists of mining components (e.g., plant, FTB, pits, stockpiles, transportation corridor, etc.) and engineering controls (e.g., liners, covers, WWTF, PRBs, etc.) that work as a system to accomplish the purpose of the Proposed Project and manage environmental impacts to water resources resulting from mining activities. The Proposed Project also includes a process by which 1) the engineering controls are implemented and adapted, if justified, (this document) and 2) the mining components are reclaimed and closed (Reference (7)). Financial assurance will be provided to implement engineering controls as necessary to meet environmental standards and reclamation activities described in the Proposed Project. The Proposed Project does not include contingency mitigation.

Engineering Controls: Proposed Project elements that are fixed or adaptable that control the environmental impacts of the Proposed Project to water resources. Fixed engineering controls are not modified during the life of the Proposed Project. Adaptable engineering controls may change, if justified, either in scale or type. All engineering controls are included in the water quality modeling of the Proposed Project and work in combination with one another to meet water resource objectives. Engineering controls are not contingency mitigation.

Adaptive Water Management Plan (AWMP): A management plan that describes the various aspects of adaptive engineering controls. The AWMP references other Management Plans that contain descriptions of fixed engineering controls, contingency mitigation and other details such as monitoring protocols. Contingency mitigation is not contained in the AWMP.

Contingency Mitigation: Feasible actions that could be undertaken should engineering controls fail to control Proposed Project impacts to water resources. These are not a part of the Proposed Project and are not modeled as part of the Proposed Project. Once permitted, contingency mitigation would only be used if engineering controls are not effective in keeping the Proposed Project in compliance with water resources objectives. If monitoring or modeling indicates contingency mitigation is needed, it would become an engineering control and be financially assured. Though contingency mitigation is not a part of the Proposed Project, it is a component to the adaptive management sections contained in Management Plans.

Management Plans: Documents that describe the Proposed Project in detail, fixed and adaptive engineering controls and contingency mitigation. These plans form the basis for the Proposed Project definition. Note that Management Plans also include adaptive management and contingency mitigation for aspects of the Proposed Project other than water resources including air, wetlands and geotechnical.

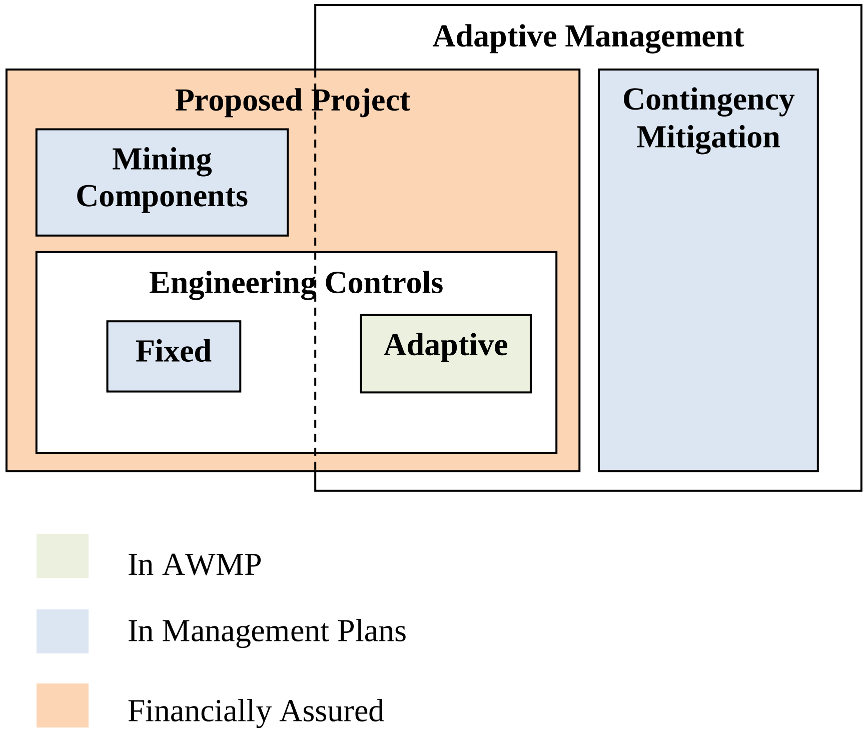

Figure 1-1 Definitions Illustrated

1.4 Process

Initial engineering controls to manage water quality have been designed based on modeling using an integrated probabilistic model (Sections 3.1 to 3.3 of Reference (8) (8), Water Quality Modeling Data Package – Mine Site, for modeling framework).

The model will be updated annually, generally as described in Section 6 of Reference (1) and Reference (2) with additional information provided by Special Performance Monitoring and Test Projects as described in the following Sections. The Special Performance Monitoring or Test Projects associated with an engineering control may evolve over time. Should that occur, the changes would be incorporated into this document and pertinent Sections of this document and related Management Plans updated.

The updated model will be used to determine if the designs of the adaptive engineering controls should be modified as described in the Modified Design portions of the following sections. If modifications are warranted, the designs in the AWMP will be updated by revising the AWMP and submitting it for approval as part of annual Permit to Mine review. The adaptive engineering controls as described in the approved AWMP will be implemented at the times defined in the approved AWMP.

It is expected that an Initial Permitting Version of this document be finalized as part of the MDNR Permit to Mine and MPCA NPDES/SDS process and that revisions to the Initial Permitting Version be made in conjunction with the annual reporting process for those permits.

Table 1-1 AWMP/Management Plan Cross Reference

AWMP Sect	Sub Sect	Engineering Control	Note	Mgmt Plan	Sect
2.0	Category 1 Waste Rock Stockpile Cover System				
2.0	2.3.2	Design	ROMP refers to AWMP for detailed design and describes adaptive engineering control	ROMP	7.1.1
2.0	2.3.4	Up Front Preparation	AWMP refers to ROMP for stockpile construction	ROMP	2.1.1.2
2.0	0	Project Monitoring	AWMP refers to WMPM for details	WMPM	5
2.0	2.5.3	Reporting and Model Update	AWMP refers to WMPM for details	WMPM	6.1-4
2.0	2.5.4	Contingency Mitigation	AWMP refers to WMPM for details	WMPM	6.5-6
2.0	2.7	Financial Assurance	AWMP refers to ROMP for reclamation estimate	ROMP	7.4
3.0	Category 1 Waste Rock Stockpile Groundwater Containment System Extension				
3.0	3.3.2	Design	ROMP refers to AWMP for detailed design and describes engineering control	ROMP	2.1.2.2 and 2.1.2.3
3.0	3.3.4	Up Front Preparation	AWMP refers to ROMP for stockpile development	ROMP	2
3.0	3.5	Project Monitoring	AWMP refers to WMPM for details	WMPM	5
3.0	3.5.3	Reporting and Model Update	AWMP refers to WMPM for details	WMPM	6.1-4
3.0	3.5.4	Contingency Mitigation	AWMP refers to WMPM for details	WMPM	6.5-6
3.0	3.7	Financial Assurance	AWMP refers to ROMP for reclamation estimate	ROMP	7.4
4.0	Category 1 Waste Rock Stockpile Groundwater Containment System Passive Treatment				

AWMP Sect	Sub Sect	Engineering Control	Note	Mgmt Plan	Sect
4.0	4.3.2	Design	WMPM refers to AWMP for detailed design and describes engineering control	WMPM	later
4.0	4.3.4	Up Front Preparation	Section 4 refers to Section 3	AWMP	3.0
4.0	4.5	Project Monitoring	AWMP refers to WMPM for details	WMPM	5
4.0	4.5.3	Reporting and Model Update	AWMP refers to WMPM for details	WMPM	6.1-4
4.0	4.5.4	Contingency Mitigation	AWMP refers to WMPM for details	WMPM	6.5-6
4.0	4.7	Financial Assurance	AWMP refers to WMPM for reclamation estimate	WMPM	7.4
5.0	Additional WWTF Capacity in Closure				
5.0	5.3.2	Design	AWMP refers to WMPM for WWTF design	WMPM	2.1.9
5.0	5.3.4	Up Front Preparation	AWMP refers to WMPM for WWTF design	WMPM	2.1.9
5.0	5.3.6	Spin Off Impacts	AWMP refers to WMPM for WWTF solid waste	WMPM	2.1.9
5.0	0	Maintenance Program	AWMP refers to WMPM for WWTF details	WMPM	2.1.9
5.0	5.5	Project Monitoring	AWMP refers to WMPM for details	WMPM	5
5.0	5.5.3	Reporting and Model Update	AWMP refers to WMPM for details	WMPM	6.1-4
5.0	5.5.4	Contingency Mitigation	AWMP refers to WMPM for details	WMPM	6.5-6
5.0	5.7	Financial Assurance	AWMP refers to WMPM for reclamation estimate	WMPM	7.4
6.0	West Pit Overflow Passive Treatment				
6.0	6.3.2	Design	MP refers to AWMP for detailed design	MP	6.2.5.2
6.0	6.3.4	Up Front Preparation	AWMP refers to MP for West Pit Outlet Structure design	MP	6.2.5.2
6.0	6.5	Project Monitoring	AWMP refers to WMPM for details	WMPM	5

AWMP Sect	Sub Sect	Engineering Control	Note	Mgmt Plan	Sect
6.0	6.5.3	Reporting and Model Update	AWMP refers to WMPM for details	WMPM	6.1-4
6.0	6.5.4	Contingency Mitigation	AWMP refers to WMPM for details	WMPM	6.5-6
6.0	6.7	Financial Assurance	AWMP refers to WMPM for reclamation estimate	WMPM	7.4
7.0	FTB Adaptive Water Management				
7.0	7.3.2	Design	WMPP refers to AWMP for detailed design	WMPP	2.1.4
7.0	7.3.3	Design	AWMP refers to WMPP for other water management systems	WMPP	2
7.0	7.3.4	Up Front Preparation	NA	NA	NA
7.0	7.5	Project Monitoring	AWMP refers to WMPP for details	WMPP	5
7.0	7.5.3	Reporting and Model Update	AWMP refers to WMPP for details	WMPP	6.1-4
7.0	7.5.4	Contingency Mitigation	AWMP refers to WMPP for details	WMPP	6.5-6
7.0	7.7	Financial Assurance	AWMP refers to WMPP for reclamation estimate	WMPP	7.4
8.0	Cell 1E/2E Enhanced Cover System				
8.0	8.1	Design	AWMP refers to FTMP for detailed design	FTMP	7.2
8.0	8.3.2	Design	AWMP refers to FTMP for detailed design	FTMP	7.2
8.0	8.3.4	Up Front Preparation	NA	NA	NA
8.0	8.5	Project Monitoring	AWMP refers to WMPP for details	WMPP	5
8.0	8.5.3	Reporting and Model Update	AWMP refers to WMPP for details	WMPP	6.1-4
8.0	8.5.4	Contingency Mitigation	AWMP refers to WMPP for details	WMPP	6.5-6
8.0	8.7	Financial Assurance	AWMP refers to WMPP for reclamation estimate	FTMP	7.4
9.0	Flotation Tailings Basin Seepage Passive Treatment				

AWMP Sect	Sub Sect	Engineering Control	Note	Mgmt Plan	Sect
9.0	9.3.2	Design	MP refers to AWMP for detailed design	WMPP	6.2.5.2
9.0	9.3.4	Up Front Preparation	Section 9 Refers to Section 7	AWMP	7.0
9.0	9.5	Anticipated Project Monitoring	AWMP refers to WMPP for details	WMPP	5
9.0	9.5.3	Reporting and Model Update	AWMP refers to WMPP for details	WMPP	6.1-4
9.0	9.5.4	Adaptive Management and Contingency Mitigation	AWMP refers to WMPP for details	WMPP	6.5-6
9.0	9.7	Financial Assurance	AWMP refers to WMPP for reclamation estimate	WMPP	7.4

1.5 Assessment of Water Quality Impacts

Each engineering control included as part of the AWMP is assessed, in part, based on how it affects the Project's ability to meet applicable water quality standards at the evaluation locations. For each engineering control, the applicable standards and evaluation locations that are most relevant to assessing the specific engineering control are identified under the Resource Objectives subsection. The actual impact the engineering control has on the probability of the Project to meet the resource objectives is assessed in the Impact on Compliance subsections. This assessment compares the performance of the project with and without the engineering control and focuses on the constituents that do not meet the resource objectives. This assessment does not consider aluminum, iron, or manganese. These constituents are being assessed in a semi-quantitative method due to high baseline concentrations and simplifying assumptions associated with the modeling of these constituents (Reference XX). In addition, beryllium in groundwater isn't considered due to background concentrations that are above the applicable groundwater standard. These constituents will be discussed in the reporting of model reports in Reference XX.

2.0 Category 1 Waste Rock Stockpile Cover System

2.1 Project Feature

The Category 1 Waste Rock Stockpile is the only permanent waste rock stockpile and will contain about 167 million tons of low sulfur (maximum of 0.12%; average 0.06%) waste rock that is not projected to generate acid but is projected to release dissolved solids, including sulfate and metals.

The Category 1 Waste Rock Groundwater Containment System provides the ability to collect water passing through the stockpile. During operations, this water will be treated via the WWTF and sent to the FTB or to the East Pit to flood the pit more rapidly. After closure, this water will be sent to the West Pit and will ultimately flow out of the pit both as a surface overflow and as groundwater flow through the surficial aquifer.

The Category 1 Waste Rock Stockpile has been shown by modeling to be the major source of constituent load to the West Pit, and the Category 1 Waste Rock Stockpile Cover System is the primary engineering control that mitigates that load.

The modeling construct (Reference (9), Mine Site Water Modeling Work Plan Stockpile Conceptual Model for details) that defines the impacts of the Category 1 Waste Rock Stockpile and the performance of the Category 1 Waste Rock Stockpile Cover System is:

- Release Rates for each constituent have been determined by comprehensive laboratory tests of Category 1 Waste Rock
- Scale Factor (which is used to convert release rates measured in lab-scale tests to field-scale conditions) has been determined by field data from similar stockpiles
- Mass of Waste Rock has been determined from the Mine Plan
- Mass of each Constituent is Release Rate X Scale Factor X Mass of Waste Rock
- Volume of Water is the amount of precipitation passing through the cover system which is a function of the area of the stockpile and the percolation rate that results from the cover system design
- Potential Concentration of each Constituent is Mass of Constituent / Volume of Water
- If the Potential Concentration is greater than the Concentration Cap (physical limit) then the Concentration is the Concentration Cap – otherwise the Concentration is the Potential Concentration

- Any Constituent Mass retained in the stockpile due to Concentration Caps is released from the stockpile at the level of the Concentration Cap until fully depleted from the waste rock

The model conservatively assumes that the oxidation process will not be limited by oxygen and that all constituents released from the rock will ultimately be transported out of the stockpile regardless of the type of cover implemented. Collectively this means that the constituent load can only be modeled to be reduced by limiting the amount of water passing through the cover system to the point where concentration caps will come into effect; therefore this engineering control improves the cover system on the stockpile, thus reducing the amount of water passing through the waste rock.

2.2 Resource Objectives

The resource objectives are to meet the applicable water discharge limits at the point where the West Pit overflow discharges to a small watercourse that flows to the Partridge River and to meet the applicable groundwater standards in the surficial aquifer downgradient of the West Pit. The applicable discharge limits will be determined in permitting. At this time, the applicable surface water quality standards (Reference (9), Tables 1-3 and 1-4) are assumed to be the applicable discharge limits and the applicable groundwater standards (Reference (9), Table 1-2) are assumed to be applicable at the property boundary. The engineering control that produces a 90^{th} percentile probabilistic water quality impacts model result being below the applicable discharge limit and groundwater standard is assumed to meet the objectives.

Note that this engineering control alone cannot achieve the objectives. The engineering controls described in Sections 3.0 through 5.0 are also required to reduce the load of constituents (Co, Cu, Ni, Pb, Sb, Se and SO_4) into the West Pit and the engineering control described in Section 6.0 is required for final passive treatment of some constituents (Co, Cu, Ni, and Pb).

2.3 Planned Engineering Control

2.3.1 Purpose

The purpose of the Category 1 Waste Rock Stockpile Cover System is to reduce the flow of water into the stockpile sufficiently beyond the point that concentration caps are reached so that constituent load from the stockpile is reduced.

The current model utilizes a geomembrane cover system with lognormal distribution for percolation through the cover system. Distribution fit points are based on Hydrologic Evaluation of Landfill Performance (HELP) Modeling which yielded 0.09 inches per year (at 2 defects per acre) and 0.42 inches per year (at 10 defects/acre) percolation through the cover system into the stockpiled waste rock. Actual monitoring of Project water quality parameters and annual updating of the model will determine if different percolation rates are actually occurring and required to be modeled.

2.3.2 Design

The engineered geomembrane cover system to be used for final reclamation of the Category 1 Waste Rock Stockpile will meet the requirements of Minnesota Rules 6132.2200 Subpart 2B.

The engineered cover system that achieves the required prevention of percolation is a geomembrane cover system. See Section 2.4 for a discussion on the basis for the required percolation rate value. The Category 1 Waste Rock Stockpile cover will consist of, from top to bottom, 18 inches of rooting zone soil consisting of on-site overburden mixed with peat soils as needed to provide organic matter, 12 inches of granular drainage material to facilitate lateral drainage of infiltrating precipitation and snowmelt off the stockpile cover, the geomembrane barrier layer, a 6-inch soil bedding layer below the geomembrane, followed by the waste rock contained in the stockpile. To minimize the potential for clogging of the granular drainage material, shallow-rooted grasses will be specified for the cover vegetation seed mix. This is standard practice for most cover systems despite the increased interest in utilizing deeper rooted vegetation types, shrubs and trees for closure vegetation. Surface drainage channels and down shoots will aid in directing clean surface water runoff from the stockpile, thereby limiting precipitation infiltration and build-up of hydraulic head in the geomembrane cover soils. Re-design of the stockpile to accommodate the geomembrane has been completed, as shown in Figure 2-1 and Figure 2-2, which show the Mine Year 11 stockpile interim configuration with waste rock at the angle of repose and the closure configuration with waste rock at 3.75H:1V fill slopes, respectively. With this stockpile re-design, the surface water drainage features have been re-evaluated for the stormwater modeling at the Mine Site, with changes as described in Section 2.3.2. Detailed design of these drainage features will be completed in permitting and will be included in this document at that time.

The stockpile will be reclaimed in closure. At that time, the process water ditch component of the Category 1 Waste Rock Groundwater Containment System will be covered, diverting non-impacted surface water runoff from the stockpile cover to the stormwater ditch system. The risers will be extended to finished cover grade to provide access for pipe cleanout, as shown on Drawing GCS-010 of Attachment C of Reference (4).

Prior to revegetation of the Category 1 Waste Rock Stockpile, the stockpile will be locally contoured to provide some topographic variety to the surface and to assist in the development of a surface drainage network. The interbench slope will be reduced to 3.75H:1V to facilitate placement of the geomembrane cover system. Drainage channels will be constructed on nominal 30-foot wide benches, constructed on nominal 40-foot vertical intervals at 2 percent typical gradients. A drainage system utilizing the benches has been developed to manage stormwater runoff from the cover. When reclamation contouring is complete, the geomembrane cover system will be constructed, and then seeded with grasses.

Stormwater runoff from the geomembrane cover will be managed using a system of top channels and outslope bench channels that convey runoff to a series of riprap-lined down chutes, as described in Reference (4). The design of top channels, outslope channels and down chutes was conducted using design criteria related to:

- The design storm event;
- Watershed characteristics;
- Design flow rates;
- Flow velocities; and
- Erosion control.

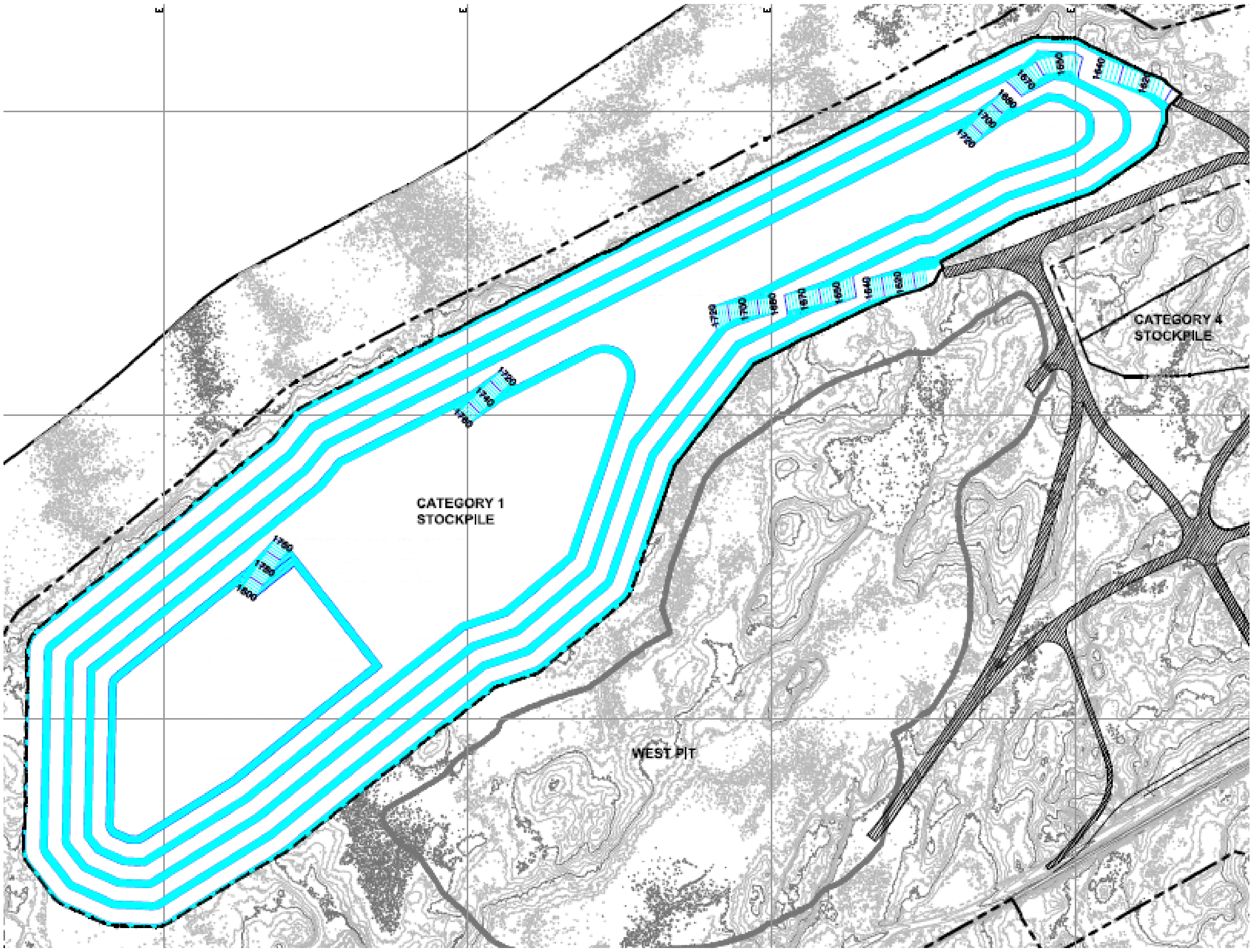

Figure 2-1 Conceptual Plan View Category 1 Waste Rock Stockpile Interim Configuration – Mine Year 11

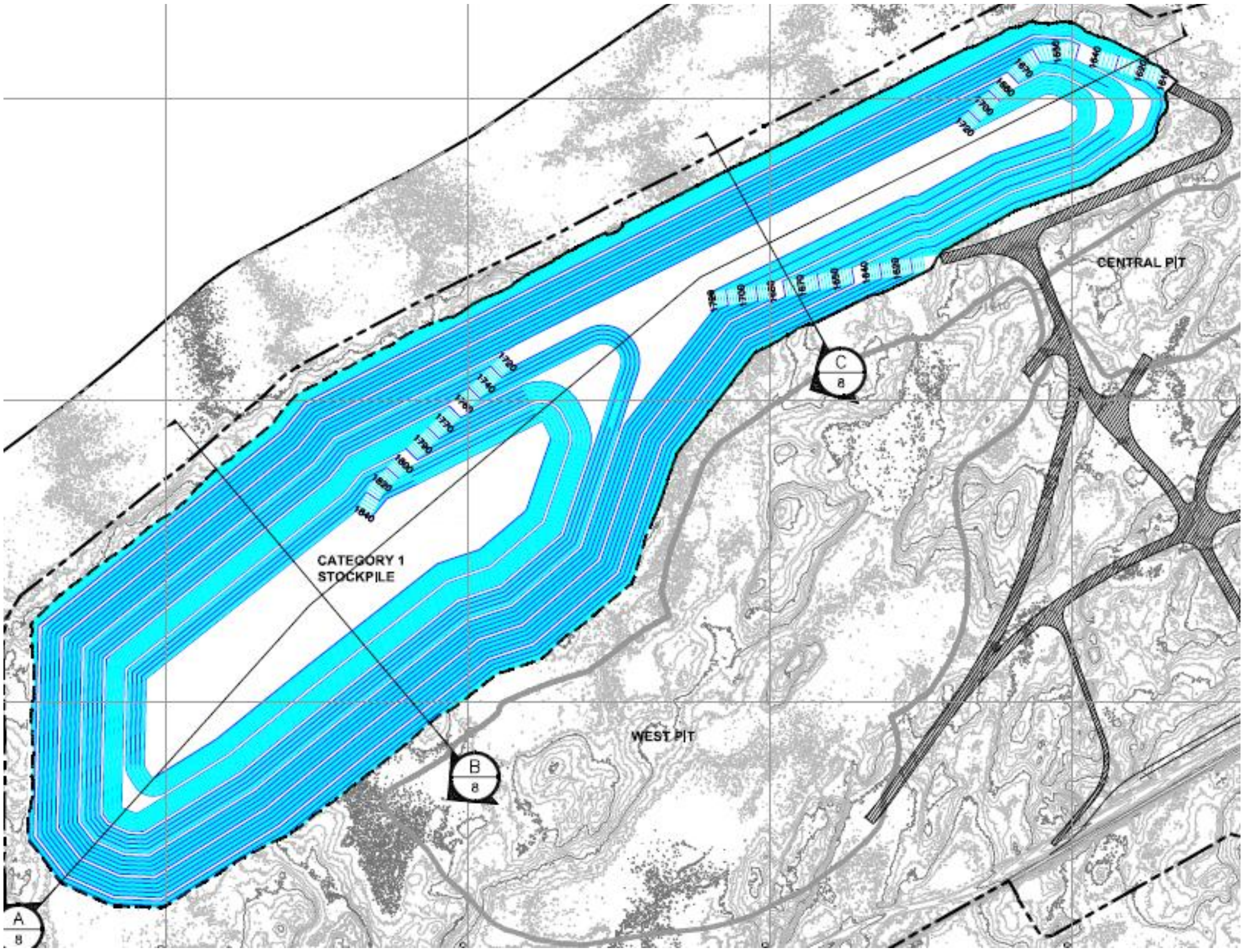

Figure 2-2 Conceptual Plan View Category 1 Waste Rock Stockpile Closure Configuration

The channels are designed to convey the estimated peak flows resulting from the design storm with runoff volume estimated using the Soil Conservation Service Curve Number (CN) method and the peak flow and routing performed using the Kinematic Wave method. The channel geometry and peak flows were used as inputs in the Manning's equation to solve for normal depth and velocity. Channels lined with riprap are designed using a minimum factor of safety of 1.5 for riprap size selection. A conventional system of outslope channels, stockpile ramp channels, down chutes and perimeter channels is designed to manage stormwater on the reclaimed stockpile outslopes. All of these channels were designed to convey the 100-year, 24-hour storm event to the perimeter stormwater ditches, as described in Reference (1). Design of the elements of the drainage system is described in Reference (4) and below.

2.3.2.1 Top Surface Grading and Drainage

The top surfaces of the reclaimed Category 1 Waste Rock Stockpile will be graded to provide a minimum nominal slope of 1.0 percent post settlement. Top surface grading (prior to reclamation) may involve redistribution of the waste rock materials to develop the finished grades.

Typical design details were developed to illustrate the management of stormwater on the regraded top surface of the stockpile. The stormwater management system consists of one or more channels on the top surface with a minimum estimated post-settlement longitudinal slope of 1.0 percent that will drain stormwater from the top surface to either down chutes or to channels along stockpile ramps.

The proposed 1.0 percent minimum top surface and drainage channel slopes are on the basis of the limited susceptibility of the stockpile to long term settlement after final top surface and drainage channel grading. In addition to the relatively low compressibility of the waste rock, the final grading will occur after the bulk of the stockpile has already been in place for 13 years (last rock to the stockpile in Mine Year 13 and cover construction starting in Mine Year 32). Therefore, unlike for municipal solid waste landfills and other solid waste management facilities where long term settlement can be expected and where 2.0 to 3.0 percent minimum slopes are warranted to accommodate future settlement; such settlement is not anticipated in the waste rock stockpile and the flatter 1.0 percent minimum slope is justified.

The top surface stormwater channels were sized to accommodate the peak discharge resulting from the 100-year, 24-hour storm within the channel with 1 foot of freeboard.

2.3.2.2 Outslope Grading and Drainage

Outslope channels are constructed on the re-graded outslope reclamation benches and spaced to limit the sheet flow distance. The stockpile outslopes will involve redistribution of the waste rock materials from angle of repose to a 3.75H:1V interbench slope with 30-foot wide benches every 150 feet, (measured from interbench slope toe to slope crest) using the maximum bench to bench elevation of 40 feet in accordance with Minnesota Rules, 6132.2400, subpart 2, item C.

Analysis of stability of cover soils on the 3.75H:1V stockpile slopes is presented in Geotechnical Data Package – Volume 3 - Version 2 (Reference (10)) . In summary, the stability of cover soils is a function of the interface shear strength between the geomembrane barrier layer and the overlying cover soil component. Interface shear strength in turn is a function of the specific soil type in contact with the geomembrane and the membrane type and surface texture (i.e., linear low density polyethylene performs differently than high density polyethylene; textured geomembrane performs differently than smooth geomembrane). As presented in Reference (10), an adequate slope stability safety factor can be achieved utilizing the geomembrane types and soil types proposed for the stockpile cover system. For reference, the State of Minnesota has previously approved and achieved success with slopes as steep as 3.5H:1V (steeper than the 3.75H:1V proposed) for cover systems utilizing geomembrane barrier layers. Slopes steeper than this may have also previously been approved but a review of State of Minnesota files to confirm this is not warranted given the pre-existing use of 3.5H:1V cover slopes.

Preliminary layouts displaying the direction of flow for the outslope bench channels have been developed with a nominal 2-percent reclamation slope. Each channel will be constructed on a 30-foot wide reclamation bench and will discharge to a down chute or stockpile ramp channel. A typical outslope channel detail was developed using the maximum estimated peak discharge and a nominal channel slope of 2 percent, resulting in a design channel depth of 2.4 feet, which includes one foot of freeboard.

2.3.2.3 Down Chutes

Down chutes will be constructed on the Category 1 Waste Rock Stockpile slopes that are reconfigured to a 3.75H:1V slope to collect and convey stormwater runoff from the outslope bench channels and top channels into perimeter channels and off-site through the stormwater system. The down chutes are designed to be constructed at a continuous 22 percent slope without grade breaks at the benches, with energy dissipation provided at the base of each down chute. The down chute channels will be armored with revetment. Revetment options include riprap or other engineered approved equivalents (e.g., articulated concrete blocks) to provide erosion protection from the potentially high velocities in the down chute channels during storm events.

An energy dissipation basin will be constructed to dissipate the high-energy flow at the outfall of the down chute channel from supercritical to subcritical flow prior to entering the perimeter stormwater channel.

2.3.2.4 Stockpile Ramp Channels

Category 1 Waste Rock Stockpile ramp channels are located along the inboard slopes of the reconstructed haul road ramps. The process water channels will be maintained during stockpile operations. While the stockpile is being reclaimed, the ramp will also be reclaimed with cover soil and the reclamation channel constructed. At this time, the ramps will be reconfigured and reclaimed to slope towards the channel at 2 percent (minimum). Stockpile ramp channels will collect flow from the top surface, outslope benches and the road surface. The stockpile ramp channels will be armored with riprap or other approved revetment. Other engineered equivalents may be used to provide erosion protection for the potentially high velocities in the stockpile ramp channels during closure and post-closure.

An energy dissipation basin will be constructed to dissipate the flow energy at the outfall of the ramp channel prior to entering the perimeter stormwater channel.

2.3.3 Degree of Use in Industry

Geomembranes have been in use in the mining industry since the 1970's (Reference (11)). Geomembrane cover systems are widely used throughout the world in the mining and other industries (power plants for coal ash, water treatment plants for filtered solids, and municipal solid waste landfills) that have to deal with disposal of solid wastes. Because geomembranes have been widely used and studied for decades, there is a high level of understanding of the geomembrane selection, design, construction and quality control procedures required for successful implementation and performance of stockpile cover systems utilizing a geomembrane as the primary hydraulic barrier component of the cover system.

2.3.4 Up Front Preparation

The plan for the Category 1 Waste Rock Stockpile must account for the fact that slopes will have to be reshaped to a slope less than the natural angle of repose that the rock slopes will have as the stockpile is developed. This is accomplished as described in Section 2.1.1.2 of Reference (4).

2.3.5 Timing and Duration of Implementation

The cover system will be implemented during mine closure and will be required to function until constituents have been depleted from the stockpile. The current model shows the time to complete depletion of the sulfur in the waste rock to have a 10th to 90th percentile range of 335 to 385 years. The estimated time (based on extrapolation of the 500 year model) to depletion of soluble metals released from the waste rock but stored in the stockpile as precipitates is more than 1,000 years.

The cover system must be functional before the West Pit overflow begins. The geomembrane cover achieves its required effectiveness immediately upon construction. But, because there is some transport delay of water passing through the stockpile, the cover system must be completed approximately 5 years before West Pit overflow begins. Because a 6 to 8 year construction period is planned due to the size of the stockpile, construction must start at the beginning of the construction season 13 years before West Pit overflow as determined by the 10th percentile lowest Mine Year in the current Project water quality model, which is Mine Year 45. This means that construction must start in Mine Year 32.

The stockpile will be left uncovered during operations and into closure to maximize the flushing of constituents from the stockpile to the WWTF via the containment system. This allowance for flushing of constituents from the stockpile shortens the time to full depletion of constituents from the rock.

In general, grading of the top of the uncovered stockpile will be gradual, in order to maximize precipitation infiltration into the stockpile for subsequent collection in the containment system. According to waste rock stockpile research by Eger and Lapakko (1985, Reference (12)), little to no surface runoff is likely to occur from the uncovered stockpile due to the coarse nature of the material. Although surface flows are not expected on a regular basis, they could occur during major storm events. Temporary dikes will be constructed along the perimeter of the stockpile top and stockpile ramps where trucks are hauling, which will minimize surface runoff over the sides. Stockpile benches may be designed to encourage infiltration and evaporation by grading the bench to flow into the stockpile, forcing infiltration or evaporation to occur. Therefore, in general, flow paths on the uncovered stockpile will direct surface flows into the stockpile or to ditches down the stockpile ramps, which will be gradual, further encouraging infiltration or evaporation.

2.3.6 Other Potential Spin-Off Impacts

Incorporation of this engineering control affects other features on the Mine Site, as follows:

- Design of the Category 1 Waste Rock Stockpile needs to consider the change in timing of reclamation and the change in slopes needed for the geomembrane cover.
- Design of the adjacent stormwater ditch and diking system needs to consider the change in timing of stockpile reclamation and a larger volume and higher flow rate of runoff from the geomembrane cover.
- Modeling of the West Pit flooding during closure needs to consider the change in timing of stockpile reclamation and a larger volume and higher flow rate of stormwater runoff from the geomembrane cover.
- Design of the adjacent Category 1 Waste Rock Stockpile Groundwater Containment System needs to consider the longer periods of time before stockpile reclamation, resulting in higher inflow rates and volumes over the life of the system, and a significant reduction in inflow rates once the geomembrane cover is in place.

2.4 Engineering Control Performance Parameters

2.4.1 Description with Basis

2.4.1.1 Mechanisms for Percolation through Geomembrane Cover Systems

Manufacturing processes and the chemical structure of polymers produce intact geomembranes with extremely low permeabilities (Reference (13)). Due to the inert chemical structure of polyethylene, intact geomembranes are essentially impermeable (Reference (14)); the majority of liquid migration through a geomembrane is due to defects introduced during manufacture or installation (Reference (15)) and the potential for defects to occur, particularly during installation, is in part dependent on the rigor of the QA/QC implemented during geomembrane installation.

Manufacturing defects have been addressed by on-line spark testing, which is an effective and reliable quality control method, and is now common practice among geomembrane manufacturers. As part of the manufacturing process, the geomembrane sheet is passed over a steel roller with a high-voltage wand placed immediately above the geomembrane. Should any pinhole defects exist in the sheet, current will pass through the pinhole triggering a shutdown in the machinery, and the sheet would then be scrapped. Spark-tested geomembrane rolls are guaranteed to have zero pinhole defects prior to installation.

Because geomembrane sheets are essentially impermeable, the magnitude of percolation through a geomembrane cover depends upon number of defects (pinholes, holes) in the geomembrane, available hydraulic head over the geomembrane to force liquid through the defects, and the characteristics of the geomembrane subgrade material, which also controls the rate of liquid migration through any defects in geomembrane sheets that go undetected and unrepaired. Each of these parameters will play a role in the performance of the geomembrane cover.

Defects in Geomembranes:

The number of defects in an installed geomembrane cover system is directly dependent on the quality of the geomembrane installation and on post-construction maintenance. Defects introduced during handling and installation may include punctures, tears, cuts, and pinhole defects in welds. Based on empirical evidence, Giroud and Bonaparte (Reference (16) and Reference (17)) concluded that most leakage through a geomembrane occurs at seams, with a defect frequency of 1 to 2 holes per acre for cases of a rigorous QA/QC program during geomembrane installation. Industry standards suggest that “excellent” installation with state-of-the-art QA/QC results in a defect frequency of 0.5 to 1 holes per acre, while a “good” installation results in 1 to 4 defects per acre (Reference (18)). The above values may be applied to account for geomembrane defects occurring at the installation seams and the accidental punctures during installation. Giroud and Bonaparte (Reference (17)) computed unitized leakage rates ranging from $1x10^{-5}$ to 0.02 gallons per acre per day when good QA/QC is performed.

Leak detection studies by Forget et al. (Reference (19)) evaluated several large-scale (greater than 2.5 acres) projects for total number of leaks in a comparison of projects with a rigorous QA/QC program to projects lacking a QA/QC program. For this study, electrical leak detection surveys were performed on exposed geomembranes (water puddle method) or on soil-covered geomembranes (dipole method). For projects with good QA/QC programs for all aspects of geomembrane construction (described below), geomembranes were tested with the water puddle method and any defects found were repaired. For covered geomembranes, this testing procedure was performed prior to covering the geomembrane, and the geomembranes were then re-tested using the dipole method after placement of the soil cover. For 80-mil geomembranes on projects with a good QA/QC program, exposed geomembranes contained an average of 1.3 leaks per acre, and soil-covered geomembranes (subjected to double testing) contained an average of less than 0.1 leaks per acre in the second test. For 80-mil geomembranes on projects lacking a QA/QC program, soil-covered geomembranes contained an average of 6.2 leaks per acre (these geomembranes were not tested prior to soil covering). In this study data was nonexistent or insufficient to enable a good representation of findings for a 40-mil geomembrane.

A survey of defects in geomembranes by Nosko et al. in 1996 (as cited by Needham et al., Reference (20)) determined that 24% of holes were caused during installation and 73% were caused by mechanical damage during placement of cover soils, whereas only 2% of defects were attributed to post-construction wear and less than 1% were test holes. In the study by Forget it was concluded that only 6% of perforations were caused during the cover material installation. Thus, the conclusion in Nosko is probably valid only in cases where no rigorous QA/QC program has been implemented (Reference (19)). Therefore, it is reasonable to anticipate that proper QA/QC during soil spreading operations will result in elimination of the majority of defects caused by cover soil placement over the geomembrane.

Defects can range widely in size, depending on the quality of the installation. Nosko and Touze Foltz in 2000 (as cited in Forget et al., Reference (19)) summarized leak size that were measured at more than 300 sites in 16 countries independent of QA/QC procedures, covered or exposed geomembranes, and geomembrane thickness. The results of this data analysis indicate that the majority of leaks are above 0.5 cm^2 and that half (50%) of the leaks fall within the range of 0.5 to 2.0 cm^2. The data also indicate that 85% of leaks are smaller than 10 cm^2. A leak size frequency plot is provided in Figure 2-3, based on these data.

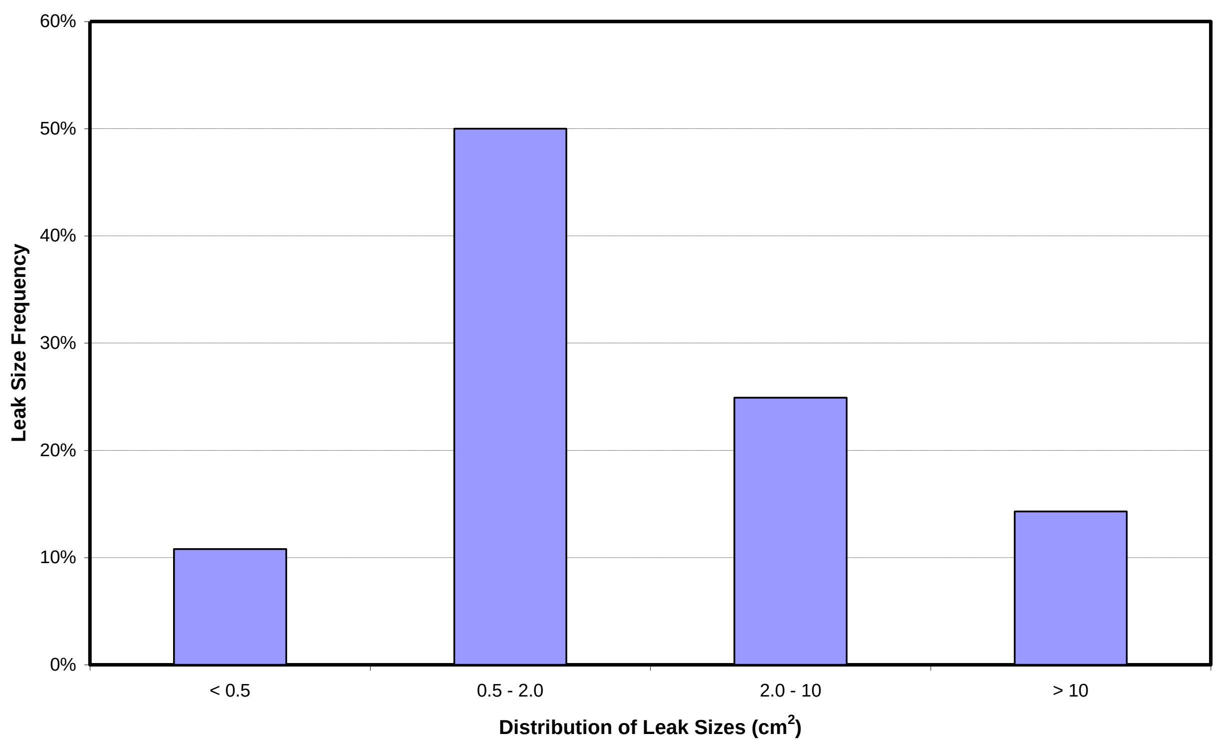

Figure 2-3 Frequency and Distribution of Leak Size
(Data from Nosko and Touze Foltz, 2000)

Based on this study by Nosko and Touze Foltz, provided that geomembrane design is adequate and good QA/QC is performed during installation, defect density and size attributed to geomembrane construction can be negligible with covered geomembranes, producing a nearly impermeable cover system. Strict geomembrane installation QA/QC is now implemented as an industry-wide standard of practice by geomembrane designers and installers (Section 2.4.1.3).

The occurrence of post-construction defects in cover systems utilizing geomembrane barrier layers has also been widely studied; primarily in the context of root intrusion through geomembranes. Such studies have been initiated based on general interest as to a geomembrane's ability to resist root penetration, and more recently by interest in establishing other than shallow-rooted grasses as the vegetative layer above cover systems utilizing clay or geomembrane barrier layer components. As evidenced by studies by Holl in 2002 (Reference (21)), EPA in 2006 (Reference (22)) and Phifer in 2012 (Reference (23)); when blocked by the presence of a geomembrane, roots grow laterally above the surface of the geomembrane rather than penetrating through the geomembrane. Further, because geomembranes are such an effective barrier to root growth, they are commercially marketed as root barriers (as cited in Phifer, Reference #). The literature indicates that geomembranes are highly effective root barriers and therefore, in cover system performance modeling, no accommodation is necessary for defects due to root penetration of the geomembrane.

Based on a limited literature search, research regarding the ability of insects and animals to burrow through geomembranes and the resulting impacts of insect and animal burrows on the integrity of cover systems utilizing geomembrane hydraulic barriers is not readily available. Crouse and Watson in 2002 (Reference (24)) indicate that research performed using rats shows the rats were unable to penetrate geomembranes. One might logically conclude that smaller animals and insects, such as pocket gophers and ants, also would be unable to penetrate geomembrane barrier layers. Given the strength and durability of polyethylene geomembranes, it is reasonable to assume that small animals and insects developing burrows in a geomembrane covered stockpile may find it difficult to penetrate the geomembrane and may abandon the burrow and/or develop a burrow of limited depth. A more extensive literature search will be required to substantiate whether animals routinely burrow through geomembrane barrier layers in cover systems. Theoretically only materials harder than a burrower’s teeth or claws can survive an attack, but vulnerability is unknown (Leon, 1997, Reference (25)). Until evidence is obtained that animal burrows through geomembranes is a significant concern, only minor accommodation for animal-related defects in geomembranes will be included in cover system performance modeling (i.e., a five-times increase in defect frequency will be modeled). Further, as indicated in a subsequent Section 2.4.2, routine inspection to observe for and remedy any animal burrows will help to minimize or prevent potential impacts from burrowing animals.

<u>Hydraulic Head above Geomembrane:</u>

The percolation rate through the geomembrane is a function of the hydraulic head above the geomembrane. Hydraulic head on the geomembrane is primarily a function of the slope of the cover system; the rate of precipitation, runoff and evapotranspiration; the hydraulic conductivity of the material overlying the geomembrane; the distance between drainage features of the cover system; and the type and density of surface vegetation and its rooting depth and density. These factors collectively determine the rate at which precipitation will build up (create hydraulic head) above the geomembrane. The hydraulic head is the force that drives liquid through the defects in the geomembrane. As hydraulic head increases, the driving force and percolation through defects in the geomembrane increases. Likewise, as hydraulic head decreases, the driving force and percolation through defects in the geomembrane decreases.

While the rate of precipitation is reasonably consistent based on site geography and climate, it cannot be controlled. However, each of the other factors that affect hydraulic head on the geomembrane can be controlled and are considered as part of stockpile cover design. The stockpile slopes, which affect the rate of surface water runoff, are selected to balance a wide range of factors such as accessibility during operations, stockpile capacity needs, long-term stability, surface water runoff control, access for maintenance, and possibly other factors. The distance between drainage features, such as mid-slope setbacks and drainage benches, are selected to facilitate long-term maintenance and surface water runoff control. Hydraulic conductivity of the soil layer immediately above the geomembrane is selected to facilitate drainage of infiltrated precipitation while also protecting the geomembrane from damage during and after installation. The type of vegetation is selected to achieve a dense vegetative cover that promotes evapotranspiration while limiting soil erosion from surface water runoff. Further, shallow-rooted vegetation is specified to limit the degree to which roots develop within and potentially clog the granular drainage layer overlying the geomembrane (the trade-off here is that roots can add strength to the cover system but slopes are flat enough that the added strength is not needed and industry practice is typically to favor shallow-rooted over deeper-rooted vegetation). These factors collectively yield a low average hydraulic head on the geomembrane cover, thus resulting in very little driving force and very low percolation through defects in the geomembrane cover.

Characteristics of the Geomembrane Subgrade Material:

After liquid passes through a defect, there is some lateral flow over and through the underlying soil prior to continued percolation and vertical migration. Therefore, computed leakage is based on the wetted soil area beneath the defect, the hydraulic conductivity of the underlying soil layer, contact between the geomembrane and underlying soil layer, and the head on the geomembrane (Reference (15)).

To summarize; the mechanisms for leakage through cover systems utilizing a geomembrane barrier layer include primarily the frequency and size of defects that remain in the geomembrane after construction is complete and all construction QA/QC has been performed, the hydraulic head above the cover system geomembrane, and the hydraulic conductivity of the soils underlying the geomembrane. This is based on a literature review, which generally documents leakage through liner systems rather than cover systems. The research likely focuses on liner systems due to the typically higher operational and closure phase hydraulic head on liner systems than cover systems (hence, potential for greater leakage rates through liners). However, because geomembrane type and manufacturing procedures, construction methods and construction QA/QC procedures are generally the same whether the geomembrane is used as a hydraulic barrier in a liner system or in a cover system, it is reasonable to assume that defect frequency in geomembrane liners and cover systems will be similar.

2.4.1.2 Methodology for Calculation of Category 1 Waste Rock Stockpile Percolation

The HELP (Hydrologic Evaluation for Landfill Performance) Model (Reference (18)) will be used to determine the percolation rate for the Category 1 Waste Rock Stockpile geomembrane cover system using the stockpile design and project climate conditions.

The HELP Model is a tool commonly used to estimate percolation through geomembrane cover systems. The HELP model was developed by the U.S. Army Corps of Engineers to provide landfill designers and regulators with a tool to quickly and economically screen alternative designs. The HELP model is a quasi-two-dimensional hydrologic model of liquid migration across, through, and out of landfills. Inputs include weather information, soil data, and cover system configuration. The HELP model accounts for snowmelt, runoff, surface storage, infiltration, evapotranspiration, vegetative growth, field capacity, lateral subsurface drainage, unsaturated vertical drainage, and percolation through cover systems. Version 3 of the model was enhanced to account for defects in geomembrane barrier layers, either due to manufacturing or installation. HELP models both surface and subsurface hydrologic processes. The major assumptions and limitations of the HELP model include:

- Runoff is computed with the SCS method, based on daily rainfall and snowmelt, assuming that the area of interest acts as an independent watershed, without receiving additional runoff from adjacent areas. This is the case for the Category 1 Waste Rock Stockpile, which is elevated with no surrounding tributary area contributing surface water run-on to the stockpile surface.

- Time distribution of rainfall intensity is not considered – while the model cannot provide accurate estimates of runoff volumes for individual storm events, the model provides reasonable long-term estimates (average annual values).

- Gravity drainage dominates the flow through homogeneous soil and waste layers and through barrier soil liners.

- Geomembranes are assumed to leak primarily through defects, input as pinholes (manufacturing defects with a diameter of 1 mm) and installation defects (holes with an area of 1 cm^2) per acre. The model assumes the hydraulic head on the defects can be represented by the average hydraulic head across the entire geomembrane cover system.

- Aging of materials can only be modeled by successive simulations; the number and size of defects cannot vary as a function of time within a single model run.

The HELP model inputs are subdivided by the layers that constitute the final cover system. These layers include the rooting zone soil (called a Vertical Percolation Layer in HELP), the granular cover soil over the geomembrane (called a Lateral Drainage Layer in HELP), the geomembrane (called the Geomembrane Barrier Layer in HELP), and the soil layer directly below the geomembrane barrier layer (also called a Vertical Percolation in HELP). HELP Model input for each layer is summarized in Table 2-1.

Table 2-1 HELP Model Input Layer Summary (Preliminary)

	Vertical Percolation Layer 1	Lateral Drainage Layer 1	Geomembrane Barrier Layer	Vertical Percolation Layer 2	Selection and/or Verification Method
Material Texture Number	8	5	N/A	22	Selected by HELP Model User
Unified Soil Classification (Typical Description)	ML (inorganic silts, very fine sands, rock flour, silty or clayey fine sands)	SM (silty sands, sand-silt mixtures)	N/A	ML (inorganic silts, very fine sands, rock flour, silty or clayey fine sands)	Help Model Default Based on Material Texture Number - Construction Specification and Construction QA/QC
Thickness (inches)	18	12	N/A	6	Construction Specification and Construction QA/QC
Porosity (Vol/Vol)	0.463	0.457	N/A	0.419	HELP Model Default Based on Material Texture Number
Field Capacity (Vol/Vol)	0.232	0.131	N/A	0.307	HELP Model Default Based on Material Texture Number
Wilting Point (Vol/Vol)	0.116	0.058	N/A	0.180	HELP Model Default Based on Material Texture Number
Initial Soil Water Content (Vol/Vol)	Calculated by HELP Model	Calculated by HELP Model	N/A	Calculated by HELP Model	HELP Model Default Based on Material

					Texture Number
Saturated Hydraulic Conductivity (cm/sec)[1,2]	3.7×10^{-4}	1.0×10^{-3}	4.0×10^{-13}	1.9×10^{-5}	HELP Model Default Based on Material Texture Number -- Construction Specification and Construction QA/QC for Lateral Drainage Layer
Root Channels[3]	Approx. 4.2	N/A	N/A	N/A	HELP Model Default Based on Vegetation Quality
Surface Slope[2]	Per Design	Per Design	N/A	N/A	Construction Specification and Construction QA/QC
SCS Runoff Curve Number	Calculated by HELP Model	N/A	N/A	N/A	HELP Model Default Based on Surface Material Texture Number, Vegetation Quality and Surface Slope
Uninterrupted Slope Length (feet)[2]	Approx. 150	Approx. 150	N/A	N/A	Construction Specification and Construction QA/QC
Vegetation Quality	Good Stand of Grass	N/A	N/A	N/A	Specified by HELP Model User
Fraction of Area Allowing Runoff	100%	N/A	N/A	N/A	Specified by HELP Model User on

					Basis of Site Geometry
Evaporative Zone Depth (inches)	12	N/A	N/A	N/A	Specified by HELP Model User
Geomembrane Installation Quality	N/A	N/A	Good	N/A	Specified by HELP Model User
Defects Frequency	N/A	N/A	Input range supported by 2.4.1.1	N/A	Specified by HELP Model User
Defect Size	N/A	N/A	1.0 cm^2	N/A	HELP Model Default

[1]Saturated Hydraulic Conductivity – for cover construction projects it is standard practice to specify the saturated hydraulic conductivity of only the Lateral Drainage Layer. While default saturated hydraulic conductivity values for Vertical Percolation Layers are used to facilitate HELP Modeling; carry-over of these values to Construction Specifications and Construction QA/QC is not typical and is not proposed.
[2]The Saturated Hydraulic Conductivity of 1.0 x 10^{-3} cm/sec for the Lateral Drainage Layer in combination with the Uninterrupted Slope Length and the Surface Slope may not adequately maintain hydraulic head on the geomembrane cover to equal or less than 1.0 foot (the thickness of the lateral drainage layer) as desired, particularly in flat slope areas (i.e., areas having 1.0 % slope). During final design, the combination of Saturated Hydraulic Conductivity, Uninterrupted Slope Length and Surface Slope will be adjusted as needed to limit hydraulic head on the geomembrane cover to equal or less than 1.0 foot.
[3]Root Channels – an empirical factor utilized by the HELP Model to increase the hydraulic conductivity of the top soil layer (Vertical Percolation Layer 1) to account for the effects of root channels on soil hydraulic conductivity.

Of note in the preceding table is the use of “Good” geomembrane installation quality. HELP Model choices for installation quality are as follows: Excellent (up to 1 defect per acre), Good (1 to 4 defects per acre), Fair (4 to 10 defects per acre) and Poor (10 to 20 defects per acre). At the time that the HELP User’s Manual was prepared, the available data showed that “Excellent” installation occurred 10% of the time, “Good” and “Fair” installation occurred 40% of the time each, and “Poor” installation occurred 10% of the time. This was before the routine use of electrical leak location surveys (which are very effective at locating defects); hence it is reasonable to assume now that the frequency of “Good” installations is high and that “Excellent” installations also routinely occur. This is supported by the research previously reported in Section 2.4.1.1. Further, anecdotal evidence from Barr Engineering geomembrane projects indicate that geomembrane defect frequency is typically well below 2 defects per acre, and routinely below 1 defect per acre after installation and testing. The benefit of the electrical leak location survey is that the defects are identified and repaired; hence the completed geomembrane barrier after QA/QC is well below 1 defect per acre and likely approaching 0 defects per acre on a routine basis. However, for HELP Modeling, a more conservative approach has been taken by modeling with 2 defects per acre and with 10 defects per acre (a five-times increase from 2 as described in Section 2.4.3).

2.4.1.3 Cover Construction Quality Assurance/Quality Control (QA/QC)

Construction QA/QC for cover systems includes documenting compliance with the specifications, material testing during construction, and conformance testing of materials before they arrive on site. Specification requirements include earthwork procedures, material testing, installation procedures, geomembrane seam testing (destructive and non-destructive), visual inspections, and specific installation requirements.

In general, geomembrane QA/QC dictates panel deployment, trial welds, field seaming, field testing (destructive and non-destructive), and repair of defects. The QA/QC manual includes test methods, test parameters, and testing frequencies. Documentation from QA/QC personnel records observations of the geomembrane during storage, handling, seam preparation, seam overlap, and verification of the adequateness of the underlying soils.

Destructive geomembrane testing involves removing a sample from the geomembrane or seam for on-site QC testing by the geomembrane installer and for QA testing by an independent third party (Reference (26)). Destructive testing of geomembrane seams includes shear testing and peel testing. Geomembrane sheet destructive testing involves tensile testing. Minimum frequencies of sampling and testing are set forth in ASTM standards and dictated in project specifications. If destructive test results do not meet acceptance criteria, additional testing proceeds in the immediate area to determine the extent of low quality seaming. This allows failing areas to be corrected with such measures as re-seaming or seaming a cap over the affected area (Reference (26)).

Common non-destructive methods for testing seams include pressure testing for double fusion welds and vacuum testing for extrusion welds. Electrical leak detection tests or surveys are also used to identify defects in the sheet and in extrusion welds. This method provides a proactive approach to locating and repairing leaks in the constructed geomembrane cover system. Electrical leak detection was developed in the early 1980's and has been commercially available since the mid-1980's. Test methods are outlined in ASTM Method D6747, D7002 and D7007. In these test methods a voltage is placed across the geomembrane through conductive materials, such as soil, above and below the membrane. Because a typical geomembrane is relatively non-conductive, discontinuities in electrical flow indicate a leak in the geomembrane (i.e., the current passes through the leak to the conductive materials surrounding the geomembrane). Electrical leak detection can be applied to both exposed and covered geomembranes in order to reveal defects caused during geomembrane installation and placement of cover soils, respectively.

The minimum detectable leak size for electrical leak detection ranges from 0.006 cm^2 to 0.323cm^2, depending on the specific method used. Based on Figure 2-3, less than 10% of geomembrane defects expected would fall below this size range. The data therefore indicates that the vast majority of geomembrane defects can be detected and repaired using an electrical leak detection test to greatly reduce the likelihood of geomembrane defects going undetected and unrepaired.

Cover soils are specified to be free-draining to provide a highly transmissive layer to ensure low hydraulic head on the cover system. Laboratory testing is conducted for the specific cover soil materials during the selection of the geomembrane. Cover soils must be spread in such a manner as to minimize geomembrane damage during cover soil placement. There is a well-established procedure for placing cover soils to minimize the potential for damaging the geomembrane, consisting of placing the cover soil in a thick lift in traffic zones and initial cover soil dumping locations, and then pushing the cover material from these locations to the specified lift thickness using a low ground pressure dozer. Depending on the configuration of the cover system, electrical resistivity leak location surveys are then performed to detect damage that may have occurred. Alternatively, continuous visual observation of cover soil placement and spreading is also commonly used as a means of detecting damage during cover soil placement. If damage to the geomembrane is incurred, the soil is manually removed, and the geomembrane is cleaned to allow for repair of the geomembrane. If cover soil will not be placed in a timely fashion after geomembrane deployment, a protective sheet can be used to shield the geomembrane from construction damage.

2.4.2 Maintenance Program

The planned stockpile cover system requires annual maintenance to remain effective. The annual maintenance consists of repair of erosion that threatens to expose the geomembrane. Mowing/targeted herbicide application to eliminate deep-rooted plant species is also a typical regulatory agency requirement and will be implemented as permits require. Periodic inspections (typically each spring and fall and after rainfall events approaching or exceeding the design event) will be implemented to identify any areas requiring erosion repair, to identify and resolve any impacts from burrowing animals, and to identify and resolve any other conditions that, if left unresolved, could impair cover system performance. If burrows of depth greater than the soil cover depth over the geomembrane are identified, indicating possible burrow penetration of the geomembrane barrier layer, the geomembrane can readily be uncovered and a patch placed to cover any perforations of the geomembrane that do exist.

The 40-mil high density polyethylene (HDPE) geomembrane planned for use, which will be buried with an in-service temperature (the temperature of the buried geomembrane) on the order of 70 degrees Fahrenheit and below, is predicted by the Geosynthetic Institute to have a service life on the order of 450 years (Reference (27)). Beyond 450 years, the geomembrane is still predicted to perform its intended function but with a reduction in factor-of-safety below the original design value. The Environmental Protection Agency (EPA) in their 2002 Assessment and Recommendations for Improving the Performance of Waste Containments Systems (Reference (28)) estimates the service lifetime of a 60-mil high density polyethylene geomembrane to be on the order of 970 years. Because the expected full effectiveness life of the planned 40-mil geomembrane (the membrane thickness typically used in final cover applications) is 450 years or more and full depletion of constituents from the stockpile is expected to be greater than 1,000 years, cover replacement is assumed to be required in the future.

If it is confirmed through periodic testing of the geomembrane, over the course of its life of hundreds of years, that the geomembrane no longer meets performance requirements, then replacement would occur. This will generally entail removal of surface vegetation from the site and systematic removal of each layer of soil covering the geomembrane. Once the geomembrane is exposed, it will be removed. The geomembrane subgrade will then be fine graded as needed, and a new geomembrane barrier layer will be installed using the construction and QA/QC procedures that were originally used. Procedures will be adjusted accordingly to adjust for new geomembrane types that are likely to be available hundreds of years in the future. After completion of geomembrane placement, the cover soils that were salvaged during removal will be replaced in sequence, with additional soils imported as needed to yield the specified cover soil layer thickness. Turf and erosion control will then be re-established.

If geomembrane replacement is required, it will be performed in increments consistent with the amount of area that can reasonably be replaced within each construction season. This may be on the order of 75 to 100 acres each season. Therefore, complete cover replacement will require 6 to 8 years to be accomplished.

2.4.3 Modeling of Engineering Controls

These proposed changes to the Category 1 Waste Rock Stockpile have been incorporated into the Mine Site water model. The following changes will be made to the model to reflect this engineering control:

- The stockpile will remain bare until the geomembrane is installed (no soil or evapotranspiration cover).
- Geomembrane installation will begin at Mine Year 32 and be completed 8 years after it begins.
- Percolation through the geomembrane will be modeled as an uncertain variable with a lognormal distribution, similar to the current modeling for the geomembrane liners on the temporary stockpiles. A value will be randomly-selected once per realization and will remain constant for the remainder of the realization.

  The use of an uncertain variable and lognormal distribution for modeling percolation through the geomembrane is further described in Reference (8). In summary, the Hydrologic Evaluation of Landfill Performance (HELP) Model was utilized to estimate the percolation through the geomembrane covered stockpile. Relatively flat areas (1.0% slope areas) of the stockpile were modeled and the 3.75H:1V slope areas (26.7% slope areas) of the stockpile were modeled. For the mean stockpile case as modeled, with the expected geomembrane defect density, percolation of precipitation through flat areas of the cover is calculated to be 0.76% of precipitation. Percolation of precipitation through the side slopes of the stockpile is calculated to be 0.11% of precipitation. The expected “typical” stockpile percolation rate of 0.32% is established by computing the weighted average percolation through the entire stockpile ((Flat Area Percolation Rate x Flat Area) + (Sloped Area Percolation Rate x Sloped Area))/(Flat Area + Sloped Area).

A second case was modeled to represent a scenario whereby some animal burrows through the geomembrane barrier layer of the stockpile cover do occur over the long-term and are temporarily left unrepaired (i.e., it is not possible to locate and repair burrows through the geomembrane, if they occur, immediately upon their occurrence). This is modeled by assuming that the defect frequency on the entire stockpile increases to 10 defects per acre. For this case, percolation through flat areas increases to 3.40% of precipitation and percolation through sloped areas increases to 0.59% of precipitation. The weighted average stockpile percolation rate for this case is 1.52% of precipitation, which is assumed to represent the 95th percentile of possible stockpile-wide conditions. The resulting lognormal distribution fit to the "typical" (median) and 95th percentile percolation rates, has a mean of 0.5% of precipitation and a standard deviation of 0.6% (see Figure 2-4).

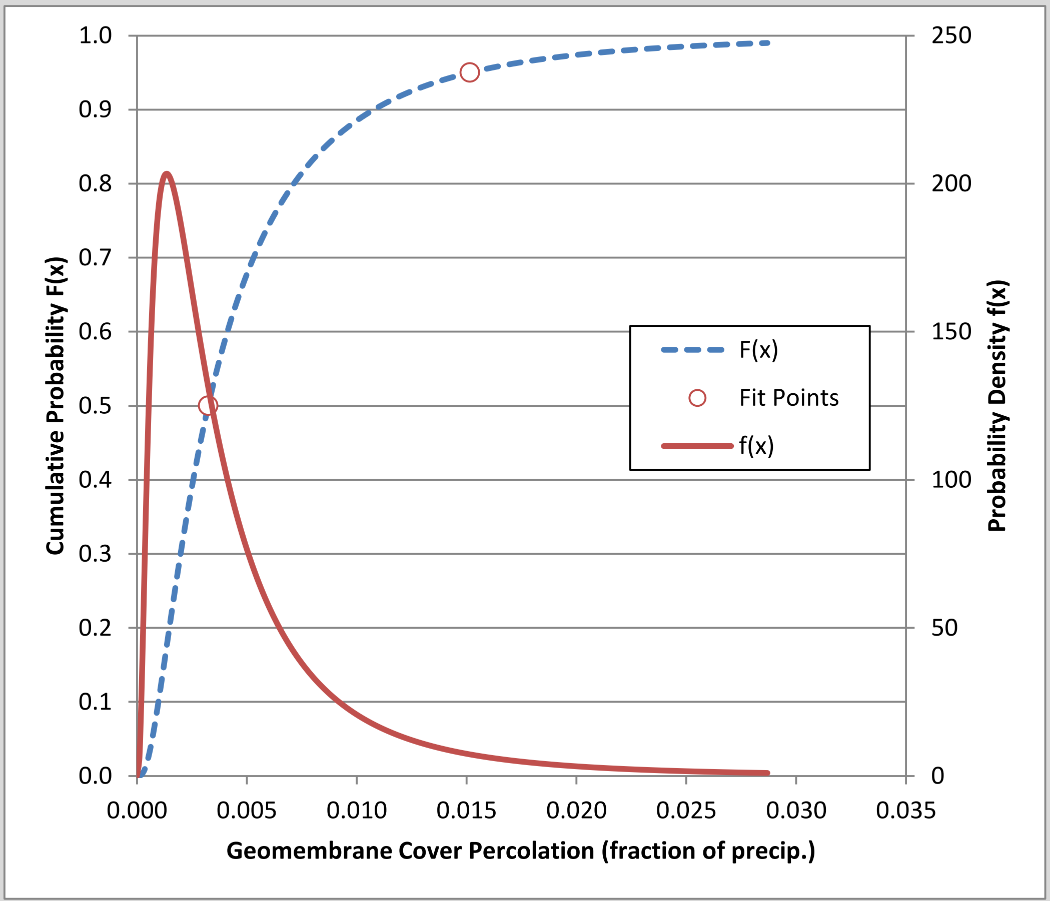

Figure 2-4 Probability Distribution for the Geomembrane Cover Percolation Rate

- The lack of organic soils below the geomembrane will remove the possible source for CO_2 enrichment. Accordingly, the stockpile pH will be assumed to range from 7.8 to 8.1 for determining concentration caps for pH-dependent constituents rather than 7.0 to 7.5 for the evapotranspiration cover which by design has a source of organic soils through which water infiltrating the stockpile must pass as described in Reference (29), Section 8.1.

2.4.4 Impact on Compliance

Table 2-2 shows the modeled measure of compliance (number of P90 results not exceeding the water quality standard / number of P90 results) for resource objectives for constituents in the West Pit overflow that do not meet resource objectives with and without the cover system. The modeling results shown here and in Sections 3.0 through 6.0 were computed using a preliminary range of percolation values (0.1 to 5% of precipitation). Refined modeling results will be provided using the distribution shown in Figure 2-4, which will result in a decreased typical and high-end flow from the Category 1 Waste Rock Stockpile to the West Pit and therefore an improvement in West Pit water quality for many constituents.

Table 2-2 Category 1 Waste Rock Stockpile Cover System Impact on West Pit Overflow

	Model Measure of Compliance	
Constituent	**No Cover System**	**With Cover System**
Co	0%	0%
Cu	0%	0%
Ni	0%	0%
Pb	100%	54.4%
Sb*	18%	17%
Se	2%	74%
SO_4*	9%	14%

Note: All Mine Site modeling assumes that all Plant Site engineering controls are in place, including water transferred to the West Pit from the Plant Site.

* Compliance is assessed in the surficial aquifer (groundwater quality) downgradient of the West Pit. For all others, compliance is assessed in the West Pit outflow (surface water quality).

The measure of compliance results presented in Table 2-2 show that the ability of the West Pit discharge to meet the resource objective for lead is decreased with this engineering control. The lead standard, which is used in this assessment, is a hardness-based standard. The engineering control decreases the concentrations of both lead and hardness in the West Pit, which lowers the lead standard and results in reduced compliance.

2.5 Anticipated Project Monitoring

The Project includes a comprehensive water quality and quantity monitoring program that will be finalized in permitting. The program includes compliance monitoring for the West Pit overflow and general performance monitoring for the Category 1 Waste Rock Stockpile (quality and quantity of the water collected by the groundwater containment system). See Section 5 of Reference (1) for details.

2.5.1 Special Performance Monitoring

The planned project monitoring will include climate data and flow from the Category 1 Waste Rock Stockpile Groundwater Containment System which will allow overall cover system performance measurement. There will be no additional performance monitoring.

2.5.2 Test Projects

A test project will be developed [detailed design in permitting and included in this document at that time] to evaluate the effectiveness of an engineering vegetated store and release evapotranspiration (ET) cover system compared to both a geomembrane cover and no cover system. This test project would be located near the Area 2 Shops, where power and buildings are currently available and no project facilities will be located to allow for long-term performance testing. A test pile or cell will be developed with each cover system with a catchment area (lysimeter) constructed below each pile/cell to allow for collection of total percolation through the pile for monitoring and analysis. Each test pile/cell would be approximately 250 tons of rock for ease of construction, and each test pile/cell will include flat areas and sloped areas similar to that planned for each stockpile construction method. The duration of the test project will be determined as part of permitting but is anticipated to be on the order of 10 to 12 years or more. This will be long enough for the cover vegetation and associated rooting system to fully develop and for typical climatic variability (wet years vs. drier years; cooler years vs. warmer years) to be captured within the test results.

2.5.3 Reporting and Model Update

The Project includes a comprehensive water quality and quantity reporting program that will be finalized in permitting. The program includes annual comparison of actual monitoring to modeled results for the West Pit overflow and Category 1 Waste Rock Stockpile. This comparison and results from Test Projects above will be used to refine the model. See Section 6 of Reference (1) for details.

2.5.4 Adaptive Management and Contingency Mitigation

The Project includes a comprehensive water quality and quantity reporting program that will be finalized in permitting. The program includes adaptive management for the West Pit water quality. See Section 6.5 and 6.6 of Reference (1) for details.

2.6 Modified Design

The annual model update may indicate a need to change the design of the cover system. The cover system design can be modified up to the point of implementation (Section 2.3.5). The current version of this document will determine the design to be implemented.

2.6.1 Circumstances Triggering Modification

Two circumstances could trigger a design modification:

1. Demonstration by actual field testing or analog sites that a modified cover design will limit the percolation rate to the extent required.

2. Demonstration by actual field monitoring of the Project and model updating that the percolation rate limit has changed and that a modified design can achieve that rate. The percolation rate limit could change for various reasons:

   a. modeled performance of other adaptive engineering controls (Sections 3.0 to 5.0) could change

   b. modeled constituent load from backfilled Category 2, 3 and 4 waste rock, pit walls or Category 1 Waste Rock Stockpile could change

   c. modeled groundwater inflow or surface runoff into the pits could change

2.6.2 Options with Increased Performance

The design of the geomembrane cover system can be adjusted to increase performance if required. Increased performance could include the following items, in order of increased performance provided:

- Increased QA/QC in overseeing construction of the geomembrane system to reduce the potential that any defects will go undetected and unrepaired during construction.

- Increased thickness of the geomembrane material to reduce the potential for defects to be created during installation and to increase the life of the geomembrane.

- Addition of a compacted soil layer below the geomembrane with decreased permeability.

- Use of a composite barrier layersystem consisting of a geomembrane with an underlying clay or geosynthetic clay liner.

2.6.3 Options with Decreased Performance

An engineered vegetated store and release evapotranspiration (ET) cover system that would achieve the required percolation rate limit would be a preferred design, because it develops into a nearly self-sustaining system. In other words, an ET cover would be designed to utilize vegetation types native to the area that have, over long periods of time, adapted to the climatic and soil conditions of the area. Only the engineered surface drainage channels and down chutes would require periodic inspection and maintenance. If after geomembrane cover system installation it is determined that an ET cover system will meet project objectives; rather than undertaking geomembrane replacement at the time that the geomembrane's useful life has been depleted, existing cover soils and vegetation types would be supplemented as needed to produce the required ET cover profile and thickness.

2.7 Financial Assurance

The cost for implementation of the cover system including reshaping of the stockpile, annual maintenance, test project (Section 2.5.2) and cover replacement will be included in the Contingency Reclamation Estimate that will be the basis for financial assurance. The estimate will be updated annually based on the liability at the end of the following year. See Reference (4), Section 7.4 for details.

3.0 Category 1 Waste Rock Groundwater Containment System Extension

3.1 Project Feature

The West Pit overflow is the only surface discharge at the Mine Site. During operations, the West Pit receives constituent load from the West Pit walls and the Category 1 Waste Rock Stockpile. In closure, the West Pit receives constituent load from the East Pit (walls and backfilled Category 2/3/4 waste rock), the West Pit walls and the Category 1 Waste Rock Stockpile.

The Category 1 Waste Rock Stockpile is the only permanent waste rock stockpile and will contain about 167 million tons of low sulfur (maximum of 0.12%; average 0.06%) waste rock that is not projected to generate acid but is projected to release dissolved solids, including sulfate and metals. The Category 1 Waste Rock Stockpile has been shown by modeling to be the major source of constituent load to the West Pit.

As described in Section 2.1, the Category 1 Waste Rock Groundwater Containment System provides the ability to collect water passing through the stockpile. During operations, this water will be treated via the WWTF and sent to the FTB or to the East Pit to flood the pit more rapidly. After closure, this water will be sent to the West Pit and will ultimately flow out of the pit both as a surface overflow and as groundwater flow through the surficial aquifer.

3.2 Resource Objectives

The resource objectives are to meet the applicable water discharge limits at the point where the West Pit overflow discharges to a small watercourse that flows to the Partridge River and to meet the applicable groundwater standards in the surficial aquifer downgradient of the West Pit. The applicable discharge limits will be determined in permitting. At this time, the applicable surface water quality standards (Reference (9), Tables 1-3 and 1-4) are assumed to be the applicable discharge limits and the applicable groundwater standards (Reference (9), Tables 1-2) are assumed to be applicable at the property boundary, and the 90th percentile probabilistic model result being below the applicable surface water or groundwater standard is assumed to meet the objectives.

Note that this engineering control alone cannot achieve the objectives. The engineering controls described in Sections 2.0, 4.0 and 5.0 are also required to reduce the load of constituents (Co, Cu, Ni, Pb, Sb, Se and SO_4) into the West Pit, and the engineering control described in Section 6.0 is required for final passive treatment of some constituents (Co, Cu, Ni and Pb).

3.3 Planned Engineering Control

The Category 1 Waste Rock Stockpile Groundwater Containment System originally planned for the project was designed to collect groundwater from the north, east and west sides of the stockpile and direct this water to the East and West Pits by gravity. Groundwater from the south side would flow to the pits via the glacial till surficial aquifer. This design included a road and surface water management system along the south side of the stockpile similar to those on the north, east and west sides, completely encircling the stockpile.

The current design extends the Category 1 Waste Rock Groundwater Containment System along the south side completely encircling the stockpile as shown in Figure 3-1. During operations, all water from the containment system will be pumped to the WWTF, treated and sent to the FTB or the East Pit to flood the pit more rapidly. After closure, this water will flow by gravity to the West Pit and ultimately overflow the West Pit as a surface discharge.

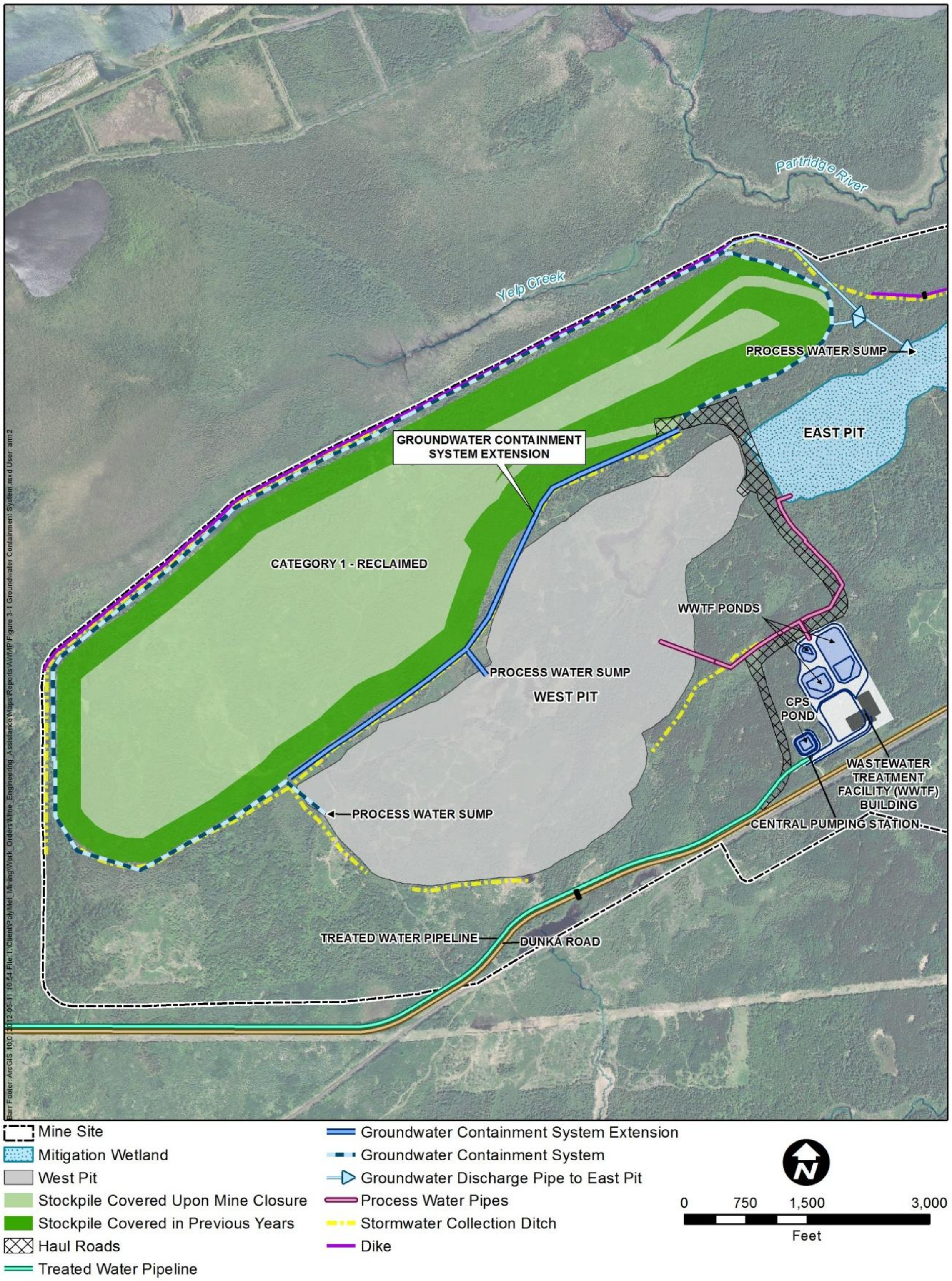

Figure 3-1 Category 1 Waste Rock Groundwater Containment System Extension

3.3.1 Purpose

The purpose of the Category 1 Waste Rock Stockpile Groundwater Containment System Extension is to provide the ability to collect and to treat practically all water from the Category 1 Waste Rock Stockpile so that constituent load from the stockpile to the West Pit is reduced.

With this engineering control in place, the current model assumes all process water from the Category 1 Waste Rock Stockpile is collected in the containment system and directed to the WWTF or the West Pit via a passive treatment system (Section 4.0). The assumption that "all" process water is collected is based on the groundwater model developed as part of the design of the containment system, as discussed in Reference (4)). The system, described further in the following section, and system effectiveness is based on the fact that water and any contained constituents will flow from locations of higher hydraulic head to locations of lower hydraulic head. The containment system piping and trench backfill is the mechanism by which the hydraulic head around the stockpile can be controlled to in turn control water flow direction. The model simulates the performance of the containment system. Actual monitoring of Project water quality parameters and annual updating of the model will confirm that flow control objectives are being achieved and/or what system modifications and operating adjustments are needed to achieve these objectives.

3.3.2 Design

A containment system will be constructed to capture stockpile drainage water recharging the groundwater system below the Category 1 Waste Rock Stockpile. The Category 1 Waste Rock Stockpile Groundwater Containment System will consist of a low permeability compacted soil barrier combined with a drainage collection system around the perimeter of the stockpile near the stockpile toe. The final configuration of the containment system will completely contain the stockpile [detailed design in permitting and included in this document].

The low permeability soil barrier, with a soil hydraulic conductivity specification of 1×10^{-6} cm/sec, will be constructed by excavating a trench near the toe of the stockpile to bedrock and backfilling the trench with a suitable compacted soil material (imported compacted natural silty clay soil or bentonite amended soil) or by placing a manufactured geosynthetic clay barrier in the trench. Any of these barrier systems will serve the intended function; exact type will be a decision made based on soil availability, overall cost, and timing/duration of construction at the point in time (i.e., spring, summer, fall) when construction services are procured and initiated. The drainage collection system will consist of a combination of pipes and ditches. This includes a slotted or perforated horizontal drain pipe surrounded by aggregate within a trench excavated to bedrock and backfilled with granular, free-draining material.

In order for the containment system to capture groundwater from the bedrock, a hydraulic connection between the drainage collection system and the bedrock must be established, and the elevation of the horizontal drain pipe must be low enough to ensure an upward vertical hydraulic gradient between the drain pipe and the bedrock. In order to establish a hydraulic connection between the collection drain and the bedrock, the existing low permeability soils below the drain pipe will be excavated down to bedrock and backfilled with a granular, high permeability material. If a hydraulic connection between the drain pipe and the bedrock is not established (e.g., if bedrock fractures were to be grouted below the drainage pipe), shallow groundwater within the bedrock will not likely be influenced by the collection drain, and an upward vertical hydraulic gradient might not be established, allowing flow to be lost beneath both the drain pipe and the low permeability soil barrier.

Stockpile drainage collected in the horizontal drain pipe will flow by gravity to a low point near the northeast corner of the stockpile. From the northeast corner of the stockpile, a non-perforated pipe will convey the flow to a collection sump where it will be pumped to the WWTF. As the stockpile development progresses to the west, another portion of the containment system will collect and convey drainage from the southwest corner of the stockpile by gravity flow to a collection sump where it will be pumped to the WWTF. The collection sumps will have emergency overflows to the East or West pits. When the WWTF ceases to operate, a passive treatment system (Section 4.0) will be implemented, and the collected water will flow to the West Pit via that system.

The horizontal drain pipe will have vertical risers extending upward into a process water ditch. The portion of the risers above ground will be slotted or perforated and encapsulated in aggregate to allow stockpile drainage water originating from surficial seeps and water collected in the process water ditch to drain via the risers into the horizontal drain pipe, while excluding soil particles of a size that could clog or otherwise be difficult to clean from the pipe. These risers will also function as access points for cleanout of the horizontal pipe. The correct specification of the aggregate and vertical riser slot size in combination with the ability to access the horizontal pipe to implement periodic preventive cleaning will minimize the risk of clogging of the drain pipe. It is common for these systems, shortly after construction and before vegetative cover is fully established, to occasionally silt in, particularly if not properly designed and constructed at the outset. The provision for multiple clean-out access points accommodates the equipment access needed to prevent and/or remedy resulting clogs, if they occur. Over the long term, once a dense vegetative cover is established, the availability of sand, silt and clay size particles to erode into the system is substantially reduced, as is the potential for clogging and the need for occasional pipe cleaning.

3.3.3 Degree of Use in Industry

Containment systems, such as the one planned, are commonly used at facilities where there is a need to manage groundwater flow, such as at landfills, tailings basins, and paper sludge disposal facilities.

3.3.4 Up Front Preparation

The ultimate footprint of the Category 1 Waste Rock Stockpile must be known so that the complete containment system can be designed. The stockpile construction sequence must be known so that an incremental construction schedule can be developed. Section 2 of Reference (3) provides that information.

3.3.5 Timing and Duration of Implementation

The Category 1 Waste Rock Groundwater Containment System will be constructed in stages from Mine Year -1 to Mine Year 6 [detailed design in permitting and included in this document].

3.3.6 Other Potential Spin-Off Impacts

Incorporation of this engineering control affects other features on the Mine Site, as follows:

- Construction of the Category 1 Waste Rock Stockpile needs to consider the development of this containment system extension along the south side.
- The design of the stormwater ditch and diking system along the south side needs to be re-evaluated to incorporate this containment system extension.
- Modeling of the West Pit flooding during closure needs to consider the reduction in volume and lower flow rates from Category 1 Waste Rock Stockpile seepage.
- Evaluation of the direct and indirect wetland impacts needs to account for the change in footprint as a result of this engineering control and associated changes in the stormwater ditch and dike designs.

3.4 Engineering Control Performance Parameters

Because the Category 1 Waste Rock Groundwater Containment System is designed so that leakage through the containment system is into the area beneath the stockpile and provisions have been made in the design to capture any flow from the stockpile via bedrock, 100% of the water passing through the stockpile is modeled to be collected.

3.4.1 Description with Basis

The containment system will create an inward hydraulic gradient toward the collection drain resulting in higher hydraulic head on the exterior/wetland side of the barrier, and lower hydraulic head on the inside/stockpile side of the barrier, where the drain is utilized to lower the water level. Because groundwater and any contained constituents move from areas of high hydraulic head to areas of lower hydraulic head, the barrier and collection drain will capture groundwater that may otherwise leave the stockpile footprint.

The drainage collection system will collect stockpile drainage and draw down the water table on the stockpile side of the barrier, thereby maintaining an inward gradient along the barrier and eliminating the potential for stockpile drainage passing through the barrier (i.e., any leakage through the barrier will be inward into the containment system).

In addition to groundwater flow in the surficial aquifer, there also exists the potential for stockpile drainage to flow within the bedrock. Groundwater flow within the bedrock is primarily through fractures, or other secondary porosity features, as the bedrock has a low primary hydraulic conductivity. At a large scale, the fractures can be assumed to be sufficiently interconnected that the fractured rock behaves similar to a porous medium.

As discussed in Section 3.3.1 and Reference (4), a groundwater flow model was developed to assess the ability of the proposed containment system to collect groundwater originating from beneath the Category 1 Waste Rock Stockpile and estimate the average, steady-state flow rate for groundwater to the collection system for the design.

Groundwater flow modeling indicates that stockpile drainage water recharging the groundwater system beneath the Category 1 Waste Rock Stockpile has the potential to flow within the bedrock prior to reaching the containment system. In order for the containment system to capture groundwater from the bedrock, a hydraulic connection between the drainage collection system and the bedrock must be established, and the elevation of the horizontal drain pipe must be low enough to ensure an upward vertical hydraulic gradient between the drain pipe and the bedrock. In order to establish a hydraulic connection between the collection drain and the bedrock, the existing low permeability soils below the drain pipe will be excavated down to bedrock and backfilled with a granular, high permeability material.

3.4.2 Maintenance Program

The planned containment system requires periodic maintenance to remain effective. Periodic maintenance will consist of inspection via video camera of the drain pipe to make sure it is not blocked by sediments or collapsed. If sediments are observed, they will be cleaned out by flushing via the vertical risers. If collapse is observed, the collapsed section will be repaired.

The periodic inspections to evaluate the need for maintenance will be every 5 years unless monitoring of the amount of water collected by the containment system indicates there has been an unusual change in flow not attributed to weather that could be caused by collapse or damage to the containment system.

3.4.3 Modeling of Engineering Controls

The proposed changes to the Category 1 Waste Rock Stockpile Groundwater Containment System have been incorporated into the Mine Site water model, with the following model changes made to incorporate this engineering control:

- All stockpile seepage will be conveyed directly to the WWTF while the WWTF is operational and will only be directed to the West Pit once the WWTF operation ceases. Prior to the extension of the containment system, some of this water flowed directly to the West Pit, even with the WWTF operational.

- The fraction of the stockpile footprint that contributes process water to the containment system will be increased to 100% at all times. This results in modeling of all process water from the stockpile as being treated at the WWTF while the WWTF is operational.

3.4.4 Impact on Compliance

Table 3-1 shows the modeled measure of compliance (number of P90 results not exceeding the water quality standard / number of P90 results) for resource objectives for constituents in the West Pit overflow that do not meet resource objectives with and without the extended containment system with the engineering control in Section 2.0 implemented.

Table 3-1 Category 1 Waste Rock Stockpile Groundwater Containment System Impact on West Pit Overflow

	Measure of Compliance	
Constituent	**No Extension**	**With Extension**
Co	0%	0%
Cu	0%	0%
Ni	0%	0%
Pb	54%	0%
Sb*	17%	18%
Se	74%	100%
SO_4*	14%	81%

Note: All Mine Site modeling assumes that all Plant Site engineering controls are in place, including water transferred to the West Pit from the Plant Site.

* Compliance is assessed in the surficial aquifer (groundwater quality) downgradient of the West Pit. For all others, compliance is assessed in the West Pit outflow (surface water quality)

3.5 Anticipated Project Monitoring

The Project includes a comprehensive water quality and quantity monitoring program that will be finalized in permitting. The program includes compliance monitoring for the West Pit overflow and general performance monitoring for the Category 1 Waste Rock Stockpile (quantity of the water collected by the containment system). See Section 5 of Reference (1) for details.

3.5.1 Special Performance Monitoring

The planned project monitoring will include climate data and flow from the Category 1 Waste Rock Stockpile Groundwater Containment System which will allow overall containment system performance measurement. There will be no additional performance monitoring.

3.5.2 Test Projects

There are no test projects planned.

3.5.3 Reporting and Model Update

The Project includes a comprehensive water quality and quantity reporting program that will be finalized in permitting. The program includes annual comparison of actual monitoring to modeled results for the West Pit overflow and Category 1 Waste Rock Stockpile. This comparison will be used to refine the model. See Section 6 of Reference (1) for details.

3.5.4 Adaptive Management and Contingency Mitigation

The Project includes a comprehensive water quality and quantity reporting program that will be finalized in permitting. The program includes adaptive management for the West Pit water quality. See Section 6.5 and 6.6 of Reference (1) for details.

3.6 Modified Design

The annual model update may indicate a need to change the design of the containment system. The containment system design can be modified up to the point of implementation (Section 2.3.5). The current version of this document will determine the design to be implemented.

3.6.1 Circumstances Triggering Design Change

Two circumstances could trigger a design modification:

1. The development of new construction materials or techniques that would achieve the required amount of water to be collected.

2. Demonstration by actual field monitoring of the Project and model updating that the required amount of water to be collected has changed and that a modified design can achieve that amount. The required amount could change for various reasons:

    a. modeled performance of other adaptive engineering controls (Sections 2.0 and 4.0 through 6.0 could change

    b. modeled constituent load from backfilled Category 2, 3 and 4 waste rock, pit walls or Category 1 Waste Rock Stockpile could change

    c. modeled groundwater inflow or surface runoff into the pits could change

3.6.2 Options with Increased Performance

No options that would increase performance are envisioned.

3.6.3 Options with Decreased Performance

Elimination of the containment system on the south side of the stockpile and relying on the West Pit to collect that water would decrease the amount of water that could be collected and treated.

3.7 Financial Assurance

The cost for implementation of the containment system including periodic maintenance will be included in the Contingency Reclamation Estimate that will be the basis for financial assurance. The estimate will be updated annually based on the liability at the end of the following year. See Reference (4), Section 7.4 for details.

4.0 Category 1 Waste Rock Stockpile Groundwater Containment Passive Treatment System

4.1 Project Feature

A passive water treatment system will be implemented as an adaptive engineering control for the drainage from the Category 1 Waste Rock Stockpile. This stockpile is the only permanent waste rock stockpile and will contain about 167 million tons of low sulfur (maximum of 0.12%; average 0.06%) waste rock that is not projected to generate acid but will release dissolved solids, including sulfate and metals for example, cobalt, copper, and nickel.

The Category 1 Waste Rock Stockpile Groundwater Containment System provides the ability to collect water passing through the stockpile. During operations, this water will be treated via the WWTF and sent to the FTB or to the East Pit to flood the pit more rapidly. During closure, this water will continue to be sent to the WWTF for about 25 to 30 years before being discharged to the West Pit. The West Pit will flood with water over approximately 25 to 30 years. Ultimately, the West Pit will have a surface overflow and a groundwater outflow through the surficial aquifer.

After operation of the WWTF has been discontinued; a passive system to treat the water collected by the containment system will be implemented as described in this Section.

4.2 Resource Objectives

The resource objectives are to meet the applicable water discharge limits at the point where the West Pit overflow discharges to a small watercourse that flows to the Partridge River and to meet the applicable groundwater standards in the surficial aquifer downgradient of the West Pit. The applicable discharge limits will be determined in permitting. At this time, the applicable surface water quality standards (Reference (9), Tables 1-3 and 1-4) are assumed to be the applicable discharge limits and the applicable groundwater standards (Reference (9), Table 1-2) are assumed to be applicable at the property boundary. The engineering control that produces a 90th percentile probabilistic water quality impacts model result being below the applicable discharge limit and groundwater standard is assumed to meet the objectives.

Note that this engineering control alone cannot achieve the objectives. The engineering controls described in Sections 2.0, 3.0, and 5.0 are also required to reduce the load of constituents (Co, Cu, Ni, Pb, Sb, Se and SO_4) into the West Pit, and the engineering control described in Section 6.0 is required for final passive treatment of some constituents (Co, Cu, Ni and Pb).

4.3 Planned Engineering Control

4.3.1 Purpose

The purpose of the Category 1 Waste Rock Groundwater Containment Passive Treatment System is to remove constituents (Co, Cu, Ni, SO_4 and Zn) in the water collected in the containment system.

The current model assumes a passive treatment system with mean percent reductions of 90% for Co, Cu, Ni, and Zn and 50% for SO_4 (for a 5-day retention time). Actual monitoring of Project water quality parameters and annual updating of the model will determine if different percent reductions are required. Site-specific pilot testing will be used to refine and improve the passive treatment system design that will achieve the required percent reductions (Section 4.5.2).

4.3.2 Design

The proposed passive treatment system for the Category 1 Waste Rock Stockpile Groundwater Containment System is a permeable reactive barrier (PRB). Sulfate is transformed in the subsurface to sulfide by sulfate reducing bacteria (Reference (30)). This process occurs in anaerobic environments and has the benefit of precipitating dissolved metals as insoluble metal sulfides. This process is enhanced *in situ* by the addition of a degradable organic substrate (Reference (31)). Other materials that can be added to supplement the process include nutrients (nitrogen and phosphorous) and zero valent iron (ZVI). The ZVI provides additional inorganic reduction within a PRB that helps to stabilize conditions that are favorable for sulfate reducing bacteria (SRB) (Reference (32)). The ZVI also provides dissolved iron to the solution that will help to bind the excess sulfide generated during the process. The portion of the PRB that contains the organic substrate and supplemental material is the treatment unit.

The basic design factors for a PRB include:

- Adequate hydraulic retention time in the treatment unit for the development of a stable microbial population. This is normally on the order of 5 days in colder climates (Reference (33)).

- A design configuration that promotes an even distribution of flow through the treatment unit. This is accomplished using gravel media and drain tile to distribute the flow throughout the treatment unit (Reference (34)).

- Placement of drain field or other access points to allow the replacement/replenishment of organic substrate and supplemental material in the treatment unit, as necessary.

An effective PRB requires an organic substrate and an adequately matched microbial community that will maintain anoxic conditions and support SRB. The submerged sediments of most natural wetlands in Minnesota contain all of the components necessary to promote sulfate reduction and metal precipitation; however, they may not have the appropriate hydraulic configuration. To provide the proper hydraulic configuration, PRB design will include delivery and collection systems on the front and back side of the treatment unit to aid in the distribution of the flow. This will consist of gravel filled trenches with distribution piping. Within the PRB treatment unit, native soils will be supplemented with degradable organic matter to promote biological activity and coarse materials (sand and gravel) to promote even distribution of the flow within the PRB. Additional basic PRB design guidance is available from numerous sources, including the ITRC (Reference (35)).

For the Category 1 Waste Rock Stockpile Groundwater Containment Passive Treatment System, the flow is expected to be 15 gpm. The required total area for a PRB is 0.33 acres, using an annual average flow of 15 gpm, a hydraulic retention time of 5 days, a minimum working treatment depth of 3 feet, and a field porosity of 30 percent as design parameters. Possible conceptual locations for multiple PRBs are shown on Figure 4-1. At least one of these locations will be used for installation of a PRB, or all three locations will be used, depending on the final hydraulic plan for discharge from the Category 1 drainage system into the West Pit. Using a PRB at each of these locations would take advantage of gravity flow, while a single consolidated PRB could be placed in one of these locations with use of pumping.

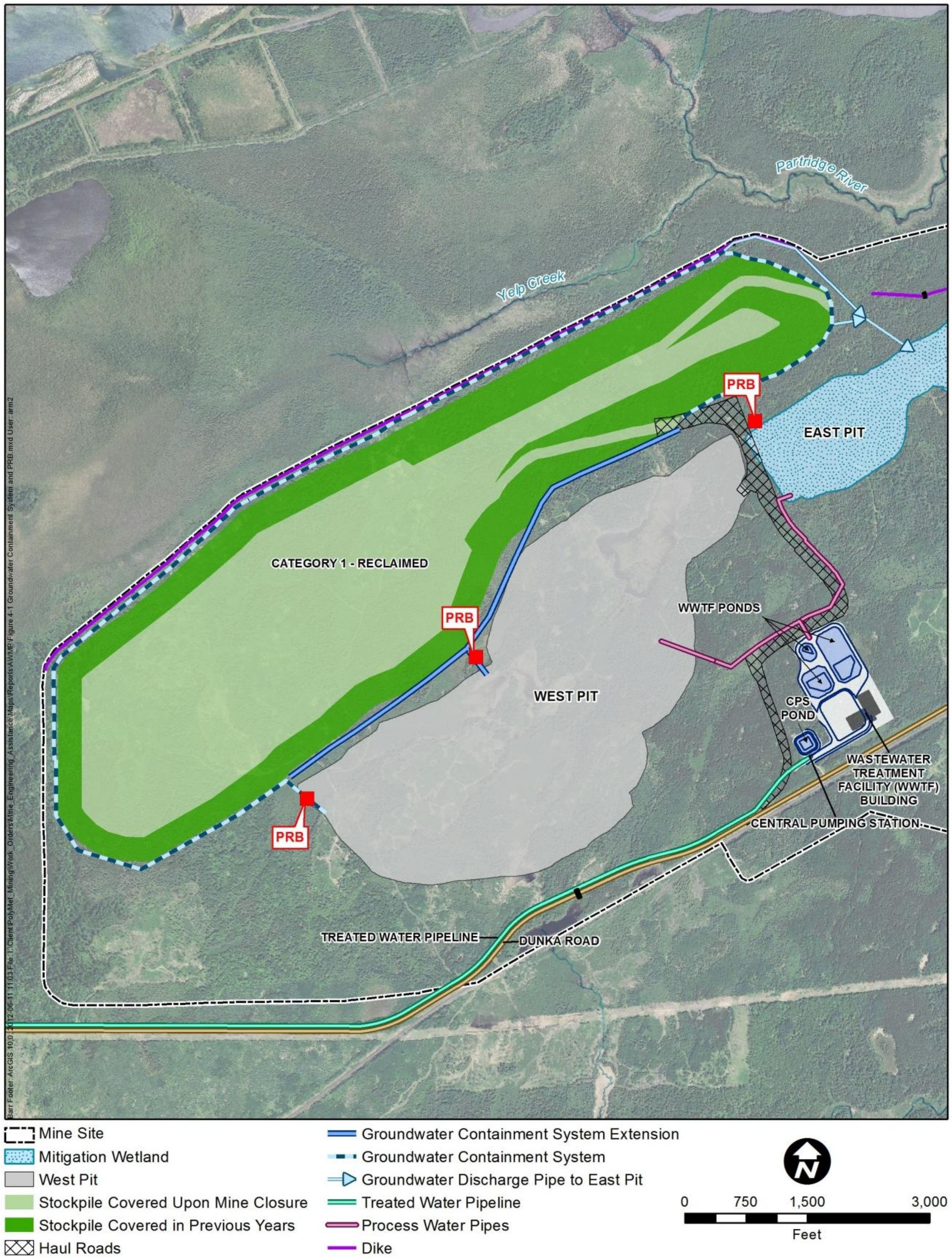

Figure 4-1 Conceptual Plan View Potential Category 1 Waste Rock Stockpile Groundwater Containment Passive Treatment System Locations

4.3.3 Degree of Use in Industry

The development and use of PRBs to treat groundwater flows was initiated in the 1990s (Reference (35)) and recently has seen extensive application to sites with groundwater impacts, including the refinement of the techniques needed to custom design PRB systems. This technology was developed as a method to enhance natural processes within the groundwater flow regime that contribute to the transformation of organic compounds or the transformation of dissolved inorganic compounds into insoluble products (Reference (35)). Most PRB systems have been installed in the subsurface for the treatment of groundwater. This configuration also facilitates year-round operation and relatively stable temperatures. Over 200 full-scale PRBs have been installed to treat groundwater at a variety of sites, and a recent guidance document on PRB systems provides 13 specific case histories of PRB implementation (Reference (35)). The development of PRBs specific to mine water drainage is an important component of PRB applications and also dates to work that originated in the 1990s (Reference (31)) as well as earlier work on passive treatment of acid mine drainage in a variety of configurations that all have similar operating characteristics (Reference (36)).

4.3.4 Up Front Preparation

The plan for the Category 1 Waste Rock Stockpile Groundwater Containment System must account for installation of the passive treatment system in closure. This is accomplished as described in Section 3.0.

4.3.5 Timing and Duration of Implementation

The passive treatment system must be functional before operation of the WWTF is discontinued. Assuming that a two year construction and biological acclimation period is required, construction must start at the beginning of the construction season three years before operation of the WWTF is discontinued as determined by the 10th percentile lowest Mine Year in the current Project water quality model.

The cover system will be implemented during mine closure and will be required to function until constituents have been depleted from the stockpile. The current model shows the time to complete depletion of the sulfur in the waste rock to have a 10th to 90th percentile range of 335 to 385 years. The estimated time (based on extrapolation of the 500 year model) to depletion of soluble metals released from the waste rock but stored in the stockpile as precipitates is more than 1,000 years.

4.3.6 Potential Spin-off Impacts

The proposed footprint for the Category 1 Waste Rock Stockpile Groundwater Containment Passive Treatment System is shown on Figure 4-1. The potential maximum additional direct wetlands impact is 0.33 acres. However, because the system will be constructed well after closure, it will be constructed, in whole or in part, on previously disturbed lands, to the extent practical to minimize wetland impacts.

The PRB will operate by gravity and is not expected to have any impacts associated with air quality or geotechnical design. The used organic substrate and supplemental material removed during periodic replacement will be disposed at an appropriate location.

4.4 Engineering Control Performance Parameters

4.4.1 Description with Basis

4.4.1.1 Percent Reduction

The primary performance parameter associated with passive treatment systems is the Percent Reduction of the constituent being treated

Influent Concentration x (1 – Percent Reduction) = Effluent Concentration **Equation 4-1**

Passive water treatment systems are capable of removing multiple constituents with similar characteristics. For example, all metals that form insoluble precipitates with sulfide can be effectively removed using the same PRB provided the proper conditions for sulfate reduction (pH, redox potential, and temperature) are established and provided sufficient sulfate is available for reduction. Both of these conditions will exist within a PRB for the treatment of the water from the Category 1 Waste Rock Stockpile Groundwater Containment System. Many of these parameters are controlled in passive water treatment systems based on the selection and placement of the solid-phase, flow-through media.

Of particular interest to this project, is a treatment system that was installed in northern Quebec at the Cadillac Molybdenum Mining site and was operated successfully through winter conditions as reported by Kuyucak, et al (Reference (37)). In this system, a solid-phase organic media was used to generate favorable conditions for sulfate reducing bacteria. The treatment system reduced copper concentrations from 300 ug/L to an average effluent concentration of 8 ug/L. Nickel and zinc reductions of an order of magnitude or more were also observed. Sulfate reduction rates were up to 75 percent with an influent value of 810 mg/L being reduced to 210 mg/L even during winter conditions. The successful winter operation of a passive system in a cold climate confirms that this engineering control is capable of significantly reducing the load of metals in the water from the Category 1 Waste Rock Stockpile Groundwater Containment System before the water enters the West Pit in closure.

Based on the work of Kuyucak, et al. (Reference (37)) the modeled percent reductions for copper, nickel, zinc, and sulfate in the PRB for Category 1 waste rock stockpile drainage are summarized in Table 4-1. While cobalt was not considered in this study, similar removal results for cobalt are also likely based on the geochemistry of cobalt in sulfate reducing conditions (Reference (38)). The modeled cobalt removal rate is also supported by small-scale testing that showed greater than 99.9 percent removal of cobalt (Reference (39)).

4.4.1.2 Media Useful Life

A secondary performance parameter associated with passive treatment systems is the media useful life. Organic substrate can be replenished naturally from plant growth (i.e., in a wetland), replacement of the solid phase media, or periodic injection of soluble organic materials. The design hydraulic loading rate for a PRB system is 15 gpm (based on preliminary modeling of the Category 1 Waste Rock Stockpile geomembrane cover discussed in Section 2.0) with an annual average sulfate mass flux of 3,000 mg/L. Using these values, the organic media requirement can be estimated based on the stoichiometric conversion of sulfate, which requires approximately 2 moles of organic carbon per mole of sulfate. Based on this value, using a conservative carbon production rate of 50 moles/m^2/yr for wetland systems (Reference (40)) would require a wetland area of approximately 9 acres to provide enough carbon for the system to be self-sustaining. Thus, the system could be made larger than the 0.33 acre footprint to eliminate maintenance activities or the organic matter produced locally on 9 acres of land could be composted and used as substrate addition.

The organic substrate within a 0.33 acre by 3 foot deep treatment volume would be expected to last approximately 20 years, assuming 50 percent of the volume is organic matter, 50 percent of the organic matter is carbon, and 50 percent of the carbon is degradable. This calculation is shown in the following Equation 4-2:

Equation 4-2

1) Annual Sulfur Load

$$= \frac{1500\ mg\ S}{L} \times \frac{15\ gal}{min} \times \frac{mmol\ S}{96\ mg\ S} \times \frac{mol\ S}{1000\ mmol\ S} \frac{1440\ min}{day} \times \frac{365\ day}{year} \times \frac{3.78\ L}{gal}$$

$$= 466{,}265\ mol\ S\ \ year$$

2) Available Carbon

$$= 0.33\ acres \times \frac{43{,}560\ ft^2}{acre} \times 3\ ft \times \frac{100\ lbs}{ft^3} \times \frac{1\ lbs\ C}{8\ lbs} \times \frac{453.5\ grams}{lb} \times \frac{mol\ C}{12\ grams\ C} = 20{,}371{,}787\ mol\ C$$

3) Useful Life

$$= 20{,}371{,}787\ \text{mol C} \times \frac{1\ mol\ S}{2\ mol\ C} \times \frac{year}{466{,}265\ mol\ S}$$

$$= 21.8\ years$$

Alternatively, replenishing a PRB system via injection of supplemental substrate such as ethanol could be considered. The annual mass of degradable organic matter consumed would need to need to contain approximately 22,400 Kg of carbon. Using a value of 1.55 Kg C per gallon of ethanol, this equates to approximately 14,400 gallons annually that could be applied through an infiltration gallery, similar to a conventional septic system drain-field.

4.4.1.3 Model Parameters

Table 4-1 summarizes model parameters that will represent the Category 1 Waste Rock Stockpile Passive Treatment System.

Table 4-1 Model Treatment Performance: Category 1 Waste Rock Stockpile Groundwater

Containment Passive Treatment System

	Percent Reduction	Basis
Cobalt	90	Laboratory study (Reference (39)) and geochemistry (Reference (38))
Copper	90	Field analog (Reference (37))
Nickel	90	Field analog (Reference (37))
Zinc	90	Field analog (Reference (37))
Sulfate	50	Field analog (Reference (37))

4.4.2 Maintenance Program

The planned passive treatment system requires periodic maintenance to remain effective. The periodic maintenance would consist of replacement of media as determined by media useful life or periodic application of liquid substrate.

Because the expected useful life of the media is 20 years and full depletion of constituents from the stockpile is expected to be more than 1000 years, more than 50 media replacements are estimated.

4.4.3 Modeling of Engineering Controls

The PRB passive treatment system for the Category 1 Waste Rock Stockpile Groundwater Containment Passive Treatment System will be incorporated into the Mine Site water model. In general, this element will have the following characteristics:

- The design flow through the PRB will be 15 gpm, on an annual average basis, as a result of the water quality modeling.
- The PRB will be incorporated into the GoldSim model as a set of percent reductions for the concentrations of a variety of constituents as listed in Table 4-1.
- No other parameters will change in the modeling.
- The performance of the PRB will not change over time.

4.4.4 Impact on Compliance

Table 4-2 shows the modeled measure of compliance (number of P90 results not exceeding the water quality standard / number of P90 results) for resource objectives for constituents in the West Pit overflow that do not meet resource objectives with and without the passive treatment system with the engineering controls in Sections 2.0 and 3.0 implemented.

Table 4-2 Category 1 Waste Rock Stockpile Groundwater Containment Passive Treatment System Impact on West Pit Overflow

	Measure of Compliance	
Constituent	**No Passive Treatment System**	**With Passive Treatment System**
Co	0%	0%
Cu	0%	0%
Ni	0%	0%
Pb	0%	0%
Sb*	18%	18%
SO_4*	81%	100%

Note: All Mine Site modeling assumes that all Plant Site engineering controls are in place, including water transferred to the West Pit from the Plant Site.

* Compliance is assessed in the surficial aquifer (groundwater quality) downgradient of the West Pit. For all others, compliance is assessed in the West Pit outflow (surface water quality)

4.5 Anticipated Project Monitoring

The Project includes a comprehensive water quality and quantity monitoring program that will be finalized in permitting. The program includes compliance monitoring for the West Pit overflow and general performance monitoring for the Category 1 Waste Rock Stockpile (quality and quantity of the water collected by the containment system). See Section 5 of Reference (1) for details.

4.5.1 Special Performance Monitoring

The planned project monitoring will include flow and water quality from the Category 1 Waste Rock Stockpile Groundwater Containment System. In order to measure passive treatment system performance, water into and out of the passive treatment system will be sampled and analyzed for the constituents of concern.

4.5.2 Test Projects

A test project will be developed [detailed design in permitting and included in this document at that time] to evaluate the effectiveness of the planned passive treatment system. A pilot scale passive treatment system of the planned design will be constructed at the Mine Site and use a slip stream of the water from the containment system as inflow.

4.5.3 Reporting and Model Update

The Project includes a comprehensive water quality and quantity reporting program that will be finalized in permitting. The program includes annual comparison of actual monitoring to modeled results for the West Pit overflow and Category 1 Waste Rock Stockpile. This comparison and results from Special Performance Monitoring and Test Projects above will be used to refine the model. See Section 6 of (Reference (1)) for details.

4.5.4 Adaptive Management and Contingency Mitigation

The Project includes a comprehensive water quality and quantity reporting program that will be finalized in permitting. The program includes adaptive management for the West Pit water quality. See Section 6.5 and 6.6 of (Reference (1)) for details.

4.6 Modified Design

The annual model update may indicate a need to change the design of the passive treatment system. The passive treatment system design can be modified up to the point of implementation (Section 4.3.5). The current version of this document will determine the design to be implemented.

4.6.1 Circumstances Triggering Modification

Two circumstances could trigger a design modification:

1. Demonstration by actual field testing or analog sites that a modified passive treatment system design will achieve the required percent reduction.

2. Demonstration by actual field monitoring of the Project and model updating that the required percent reduction has changed and that a modified design can achieve that percent. The required percent reduction could change for various reasons:

    a. modeled performance of other engineering controls (Sections 2.0, 3.0, 5.0, and 6.0) could change

    b. modeled constituent load from backfilled Category 2, 3 and 4 waste rock, pit walls or Category 1 Waste Rock Stockpile could change

    c. modeled groundwater inflow or surface runoff into the pits could change

4.6.2 Options with Increased Performance

The design of the passive treatment system can be adjusted to increase performance if required. Increased performance could include the following items, in order of increased performance provided:

- Longer retention times would allow more time for the flow to interact with the sulfate reducing bacteria within the wetland.

- Different media that could improve the rate of degradation or prolong the overall treatment - for example APTsorb material (Section 6.0) could be mixed into the PRB substrate matrix to temporarily sorb metals until they can react with excess sulfide within the treatment unit.

4.6.3 Options with Decreased Performance

The design of the passive treatment system can be adjusted to decrease performance if required. Decreased performance could include the following items, in order of decreased performance provided:

- Partial or complete bypass: A portion of the Category 1 Waste Rock Stockpile Groundwater Containment System water could be routed around the PRB system and directly to the West Pit, or the West Pit overflow treatment system

- Alternative media: different media with a longer operating life, but potentially less affinity for metal sorption could be used to decrease the performance of the system, while also decreasing the potential replacement frequency.

- Shorter retention time would extend the useful life of the solid phase organic substrate while reducing the percent reductions obtained from the treatment system.

4.7 Financial Assurance

The cost for implementation of the passive treatment system including test project (Section 4.5.2), performance monitoring (Section 4.5.1), periodic maintenance and media replacement or replenishment will be included in the Contingency Reclamation Estimate that will be the basis for financial assurance. The estimate will be updated annually based on the liability at the end of the following year. See Reference (1), Section 7.4 for details.

5.0 Additional WWTF Lead and Antimony Treatment in Closure

5.1 Project Feature

The WWTF will operate in closure to remove the flushing load added to the East Pit when the Category 2/3 and Category 4 Waste Rock Stockpiles are relocated to the East Pit and as the East Pit walls are inundated. The WWTF will also be operated to remove load associated with the flow from the Category 1 Waste Rock Stockpile Groundwater Containment System (See Section 4.1) and the flushing load from the West Pit walls during put filling. Modeling shows that the temporary antimony and lead loading from various sources will require additional treatment , as described in this Section.

5.2 Resource Objectives

The resource objectives are to meet the applicable water discharge limits at the point where the West Pit overflow discharges to a small watercourse that flows to the Partridge River and to meet the applicable groundwater standards in the surficial aquifer downgradient of the West Pit. The applicable discharge limits will be determined in permitting. At this time, the applicable surface water quality standards (Reference (9), Tables 1-3 and 1-4) are assumed to be the applicable discharge limits and the applicable groundwater standards (Reference (9), Table 1-2) are assumed to be applicable at the property boundary. The engineering control that produces a 90th percentile probabilistic water quality impacts model result being below the applicable discharge limit and groundwater standard is assumed to meet the objectives.

Note that this engineering control alone cannot achieve the objectives. The engineering controls described in Sections 2.0 through 4.0 are also required to reduce the load of constituents (Co, Cu, Ni, Pb, Sb, Se and SO_4) into the West Pit and the engineering control described in Section 6.0 is required for final passive treatment of some constituents (Co, Cu, Ni and Pb).

5.3 Planned Engineering Control

This Engineering Control will be additional water treatmentfor lead and antimony. The overflow from the chemical precipitation units will be directed to the WWTF influent, as originally planned.

5.3.1 Purpose

The purpose of Additional WWTF Lead and Antimony Treatment in Closure is to provide the capability to treat East Pit pore water and West Pit lake water so that constituent load from the flushed from the backfilled Category 2, 3 and 4 waste rock and the inundated pit walls is removed.

The current model assumes the East Pit pore water will be treated at 1,200 gpm for approximately 35 years and the West Pit lake water is treated at 1,200 gpm for 24-30 years (until the West Pit is completely flooded). The Category 1 Waste Rock Stockpile Groundwater

Containment System flow will be combined with the East Pit pore water for treatment. Actual monitoring of Project water quality parameters and annual updating of the model will determine if this can be modified.

5.3.2 Design

The detailed design for the WWTF is described in Section 2.1.9 of Reference (4). The current system should be capable of removing lead without any additional unit operations. If necessary, however, the performance of the existing chemical precipitation units could be enhanced with the addition of specialized scavenger chemicals for removal of lead and other metals. Added treatment for the removal of antimony,, would include the addition of iron oxide coated sand filtration.

5.3.3 Degree of Use in Industry

The treatment technologies used in the WWTF are commonly used.

5.3.4 Up Front Preparation

The ultimate footprint of the WWTF will accommodate addition of the additional process units for treatment. Section 2.1.9 of Reference (4) provides that information.

5.3.5 Timing and Duration of Implementation

The additional treatment must be functional for the first 35 years after mine closure. The additional treatment achieves its required effectiveness immediately upon construction. Because a one year construction period is required, construction can start at mine closure.

The WWTF will be required to function until constituents flushed from the backfilled Category 2, 3 and 4 waste rock and pit walls have been removed from the East Pit pore water and the West Pit lake. The current model shows this time to have a 10th to 90th percentile range of 24 to 30 years (after the end of mining).

5.3.6 Other Potential Spin-Off Impacts

The extended use of the WWTF and the additional capacity will require the additional consumption of power (to operate the facility) and chemicals, and will also result in the creation of additional solid wastes (precipitated gypsum and solids from filter backwash) that will need to be managed as described for the WWTF in Section 2.1.9.1.7 of Reference (4).

5.4 Engineering Control Performance Parameters

5.4.1 Description with Basis

Iron oxide coated sand filtration is one of several commercially available and demonstrated technologies that were developed for the removal of arsenic from drinking water when the primary drinking water standards were recently lowered (Reference **Invalid source specified.**).

Due to the chemical similarity of arsenic and antimony iron oxide coated sand filtration is also capable of removing antimony.

Dissolved lead can be removed from water by the conventional precipitation methods that are already planned for use in the Mine Site WWTP. However, minor modifications to the control of pH, the addition of iron salts, or the recycling of iron sludge in the first chemical precipitation reactor may be needed to optimize removal efficiencies. With the proper control of these parameters, essentially 100 percent removal of lead can be achieved by co-precipitation with iron oxide (Reference **Invalid source specified.**). Other potential modifications to improve lead removal efficiency that could also be considered, if necessary, include the addition of sulfide-based or other proprietary coagulants.

5.4.2 Maintenance Program

The WWTF requires maintenance to remain effective. The maintenance of the existing WWTF is already described in Section 2.1.9 of Reference (4).

5.4.3 Modeling of Engineering Controls

The Additional WWTF Lead and Antimony Treatment in Closure will be incorporated into the Mine Site water model. In general, this element will have the following characteristics:

- The effluent treatment target for antimony in closure will be changed to 10 µg/L
- The effluent treatment target for lead in closure will be changed to 3.2 µg/L
- All other WWTF modeling parameters will remain unchanged

5.4.4 Impact on Compliance

Table 5-1 shows the modeled measure of compliance (number of P90 results not exceeding the water quality standard / number of P90 results) for resource objectives for constituents in the West Pit overflow that do not meet resource objectives with and without the additional WWTF treatment with the engineering controls in Sections 2.0 through 4.0 implemented.

Table 5-1 Additional WWTF Capacity in Closure Impact on West Pit Overflow

	Measure of Compliance	
Constituent	**No Additional Capacity**	**With Additional Capacity**
Co	0%	0%
Cu	0%	0%
Ni	0%	0%
Pb	0%	39%
Sb*	18%	100%

Note: All Mine Site modeling assumes that all Plant Site engineering controls are in place, including water transferred to the West Pit from the Plant Site.

* Compliance is assessed in the surficial aquifer (groundwater quality) downgradient of the West Pit. For all others, compliance is assessed in the West Pit outflow (surface water quality).

5.5 Anticipated Project Monitoring

The Project includes a comprehensive water quality and quantity monitoring program that will be finalized in permitting. The program includes compliance monitoring for the West Pit overflow and performance monitoring for the WWTF (quantity and quality of water into and out of the WWTF). See Section 5 of Reference (1) for details.

5.5.1 Special Performance Monitoring

The planned project monitoring will include monitoring that will allow WWTF performance measurement. No additional performance monitoring is required for the additional WWTF treatment.

5.5.2 Test Projects

There are no test projects planned.

5.5.3 Reporting and Model Update

The Project includes a comprehensive water quality and quantity reporting program that will be finalized in permitting. The program includes annual comparison of actual monitoring to modeled results for the West Pit overflow and Category 1 Waste Rock Stockpile. This comparison will be used to refine the model. See Section 6 of (Reference (1)) for details.

5.5.4 Adaptive Management and Contingency Mitigation

The Project includes a comprehensive water quality and quantity reporting program that will be finalized in permitting. The program includes adaptive management for the West Pit water quality. See Section 6.5 and 6.6 of (Reference (1)) for details.

5.6 Modified Design

The annual model update may indicate a need to change the design of the treatment. The treatment design can be modified up to the point of implementation (Section 5.3.5). The current version of this document will determine the design to be implemented.

5.6.1 Circumstances Triggering Design Change

Two circumstances could trigger a design modification:

1. The development of new treatment technologies or techniques that would achieve the required amount of constituent removal.

2. Demonstration by actual field monitoring of the Project and model updating that the required amount of flushed constituents to be removed has changed and that a modified design can achieve that amount. The required amount could change for various reasons:

    a. modeled performance of other engineering controls mitigation (Sections 2.0 to 4.0 and 6.0) could change

    b. modeled constituent load from backfilled Category 2, 3 and 4 waste rock or pit walls could change

5.6.2 Options with Increased Performance

Performance could be increased by implementing additional stages of treatment or additional parallel treatment trains.

5.6.3 Options with Decreased Performance

Performance could be decreased by implementing fewer stages of treatment or fewer parallel treatment trains.

5.7 Financial Assurance

The cost for implementation of the treatment system including periodic maintenance will be included in the Contingency Reclamation Estimate that will be the basis for financial assurance. The estimate will be updated annually based on the liability at the end of the following year. See Reference (1), Section 7.4 for details.

6.0 West Pit Overflow Passive Treatment

6.1 Project Feature

The West Pit overflow is the only surface discharge at the Mine Site. In closure, the water quality of the water in the West Pit is an aggregation of all the potential long-term sources of load to the water, including the Category 1 Waste Rock Stockpile, the exposed East Pit walls and subaqueous Category 2/3/4 waste rock, and the exposed West Pit walls both during flooding and after the pit begins to overflow.

Treatment of the West Pit overflow is the final opportunity to apply engineering controls. Management of the flow to eliminate discharges during certain portions of the year is envisioned to comply with the sensitive period requirement for wild rice. These actions can be managed by installing the proper flow-control structures and developing the proper flow control plan.

6.2 Resource Objectives

The resource objectives are to meet the applicable water discharge limits at the point where the West Pit overflow discharges to a small watercourse that flows to the Partridge River and to meet the applicable groundwater standards in the surficial aquifer downgradient of the West Pit. The applicable discharge limits will be determined in permitting. At this time, the applicable surface water quality standards (Reference (9), Tables 1-3 and 1-4) are assumed to be the applicable discharge limits and the applicable groundwater standards (Reference (9), Table 1-2) are assumed to be applicable at the property boundary. The engineering control that produces a 90^{th} percentile probabilistic water quality impacts model result being below the applicable discharge limit and groundwater standard is assumed to meet the objectives.

Note that this engineering control alone cannot achieve the objectives. The engineering controls described in Sections 2.0 through 5.0 are also required to reduce the load of constituents (Co, Cu, Ni, Pb, Sb, Se and SO_4) into the West Pit. The engineering control described in this section represents the final opportunity for additional passive treatment of some constituents (Co, Cu, Ni and Pb).

6.3 Planned Engineering Control

6.3.1 Purpose

The purpose of the West Pit Overflow Passive Treatment System is to remove constituents (Co, Cu, Ni and Pb) in the West Pit overflow water to achieve resource objectives.

The current model assumes a passive treatment system with mean Effluent Concentrations of 2 ug/L for Co, 8 ug/L for Cu, 10 ug/L for Ni, and 3.2 ug/L for Pb. Actual monitoring of Project water quality parameters and annual updating of the model will be used to compare influent concentrations to the effluent targets and to modify the design requirements for a passive treatment system, if necessary. Site-specific pilot testing will be used to refine and improve the passive treatment system design that will achieve the required effluent concentrations (Section 6.5.2).

6.3.2 Design

The mean annual flow rate from the West Pit to the Partridge River will be 1.06 cfs. However, this volume will be discharged during only a portion of the year to achieve compliance with sensitive period water quality criteria for wild rice downstream of the Mine Site. The design of the West Pit Overflow Passive Treatment System is based on a discharge period of two months which results in the highest flow and largest treatment system. Because retention time is a key design parameter, a longer discharge period will result in a smaller treatment system. The design discharge rate is 6.35 cfs (approximately 2,850 gpm or approximately 4.1 MGD).

The modeled West Pit overflow water quality after the engineering controls described in Sections 2.0 through 6.0 have been implemented is summarized in Table 6-1 for basic parameters that will affect design of the passive treatment system and in Table 6-2 for parameters that require additional treatment or removal.

Table 6-1 West Pit Overflow Water Quality – Basic Parameters

Parameter	Median Value	Range (P10 to P90)
pH (assumed range in model)	7.25	7.05 – 7.45
Alkalinity (mg/L)	41	33 – 50
Iron (dissolved) (µg/L)	57	41 – 209
Calcium (dissolved) (mg/L)	45	25 – 70
Aluminum (dissolved) (µg/L)	1.4	0.9 – 2.1

Table 6-2 West Pit Overflow Water Quality – Treatment Parameters

Parameter	Median Value (ug/L)	Range (P10 to P90) (ug/L)
Copper (dissolved)	230	100 – 700
Cobalt (dissolved)	24	11 – 60
Nickel (dissolved)	340	200 – 590
Lead	13	11 - 15

The West Pit overflow water is modeled to have a low concentration of suspended solids and, based on the concentrations of dissolved iron and aluminum (Table 6-1), a relatively low potential to form a significant mass of metal hydroxide precipitate within a passive treatment system.

Given the low potential for sedimentation and the value of maintaining a pH with a minimum value of no less than 7.5 to minimize the solubility of metals such as copper, the planned passive treatment for the West Pit overflow is a multi-stage system consisting:

- a limestone drain for pH adjustment,
- a constructed wetland for metal precipitation and solids removal,
- a Permeable Sorptive Barrier (PSB) for polishing, and
- an aeration pond.

Figure 6-1 shows an approximate location for the West Pit overflow passive treatment system and Figure 6-2 shows a conceptual cross-section of the proposed system, showing each of the four stages. Each of these stages is described briefly in the following paragraphs.

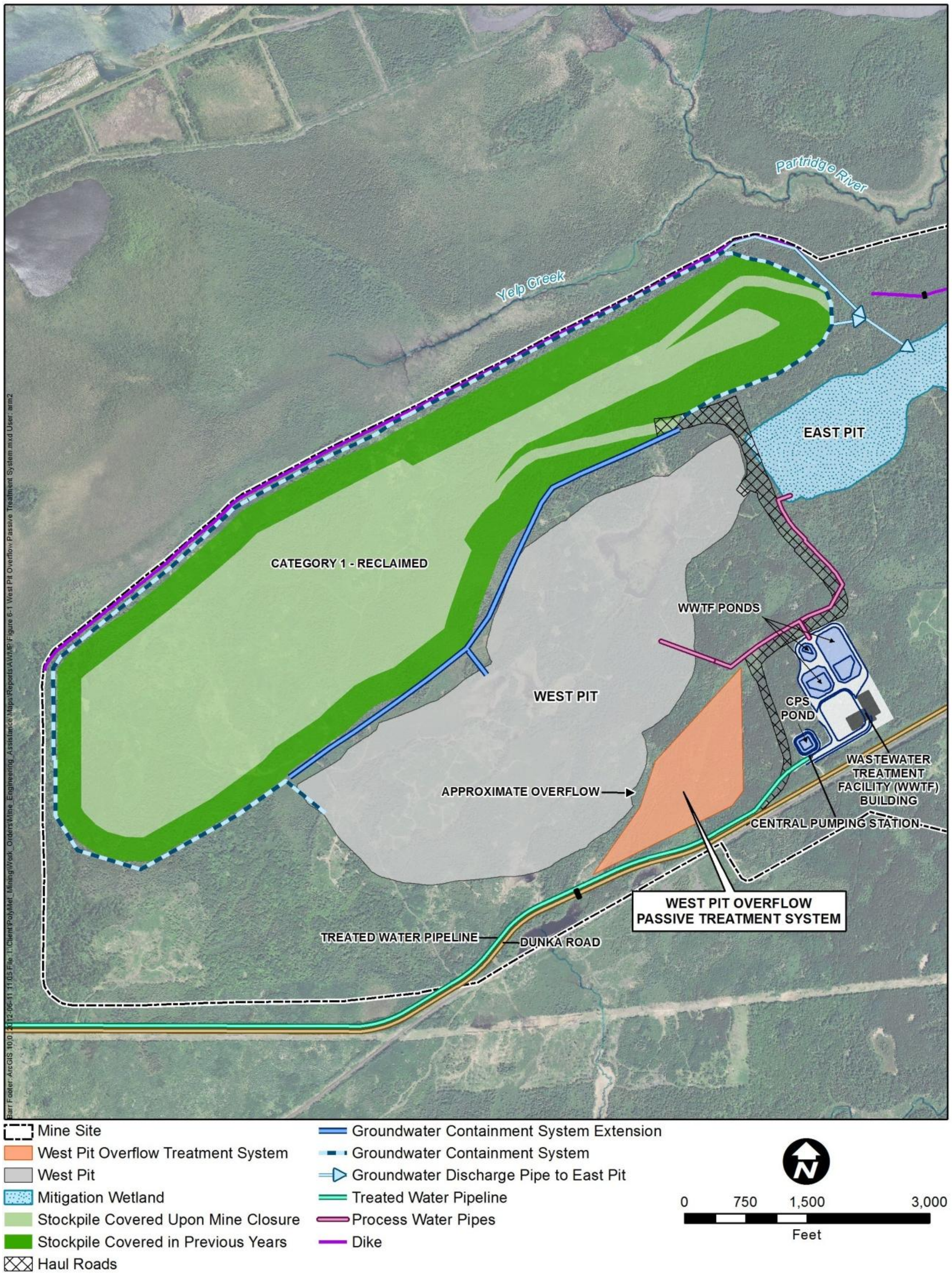

Figure 6-1 Conceptual Plan View West Pit Overflow Passive Treatment System

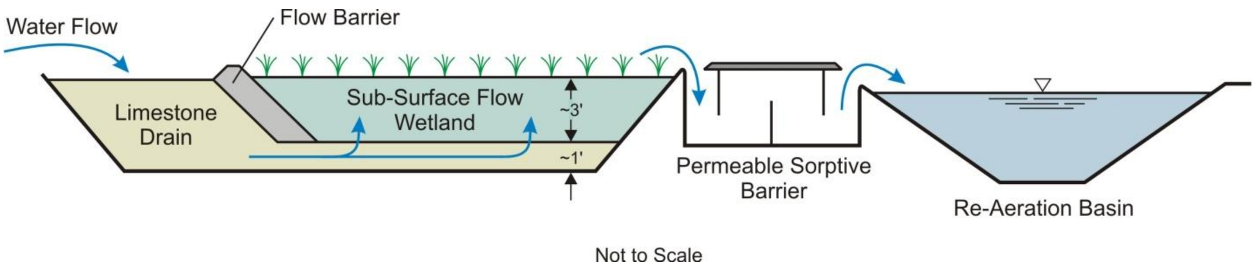

Figure 6-2 West Pit Overflow Passive Treatment

6.3.2.1 Limestone Drain

For the West Pit overflow, where the volume of iron and aluminum precipitate is expected to be minimal and where the pH is expected to be near neutral, a conservative retention time of 24 hours will be used to design the limestone drain. The material within the drain will consist of clean crushed limestone without any fines and will have a minimum dimension of one inch and a median dimension of three inches prior to placement.

Using the design discharge rate and, a design retention time of 24 hours, an operating depth of three feet, and a porosity of 30 percent, the required area for a limestone drain is approximately 12.6 acres. The drain will be located to the south and east of the West Pit outfall within the existing foot print of the Project in approximately the same location as the Overburden Storage and Laydown Area. Routing of the West Pit overflow to the limestone drain and detailed grading would be completed and incorporated into the closure plan for the site. The flow out of the limestone drain would be routed to a constructed wetland for additional treatment as described in the following Section.

6.3.2.2 Constructed Wetland

For removal of copper, cobalt, nickel, and lead; the West Pit overflow will be routed from the limestone drain to a constructed wetland.

A 48-hour retention time, a design depth of three feet, and the design flow rate results in a working wetland area of approximately 25 acres (not including ancillary working space for access roads). Additional volume (retention time) could also be created by increasing the depth, as necessary. The constructed wetland, similar to the limestone drain, will be located within the working footprint of the NorthMet operations to the southeast of the proposed West Pit overflow. The discharge from the limestone drain would flow by gravity to the constructed wetland and then by gravity out of the wetland into the PSB (Section 6.3.2.3).

The use of a limited discharge period, while resulting in a slightly larger foot print for the treatment system does have several advantages. In particular, the limited discharge avoids the need for winter operation and allows the discharge to occur during a period when the water will still be relatively warm at the end of the summer season. In addition, the limited discharge allows the wetland vegetation to build up a supply of degradable carbon within the wetland during the growing season that can be consumed by sulfate reducing bacteria and other microorganisms to support biological sulfate reduction in the fall when plant activity and the diffusion of oxygen into the subsurface decreases. During non-discharge periods, the wetland will need to be maintained in a saturated condition. This can be accomplished by limiting the outflow from the wetland during non-discharge months, and if necessary, supplementing the inflow to the wetland (above normal precipitation) to maintain saturated conditions by re-supplying any water lost to evapotranspiration during the growing season. These operations will make the wetland system self-sustaining in support of biological sulfate reduction and metal sulfide precipitation.

6.3.2.3 Permeable Sorptive Barrier (PSB)

Because of the limited discharge period, operation in winter conditions is not anticipated and the temperature range for the wetland outfall is likely to be relatively constant. Generally, a contact time of greater than 30 minutes is adequate for sorption systems. Using a conservative value of 1 hour empty bed contact time, the required volume for a sorption gate at the outfall of the constructed wetland would require a minimum volume of 23,000 cubic feet of sorptive media that would be placed at the downgradient end of the constructed wetland so that water can flow by gravity through the sorptive media and into an aeration pond as described in the following Section. Increasing the volume of the media within the sorptive barrier would decrease the required frequency for replacement of the media.

6.3.2.4 Aeration Pond

The purpose of the aeration pond is to provide time for water exiting the PSB to re-equilibrate with the atmosphere, and in particular to increase the concentration of dissolved oxygen before the water is discharged to the Partridge River. A maximum, conservative time for retention in an aeration pond would be one day. However, a cascade spillway or other design components could reduce the time required to reach equilibrium with the atmosphere. Again, the proposed limited discharge will eliminate the need to operate at a time when an aeration pond would be covered with ice or snow, thus eliminating a potential limiting rate for aeration.

For the purpose of design, a 24-hour retention time with a pond depth of 3 feet or more would require a maximum surface area of approximately 4 acres. A conceptual location for the aeration pond is in the area of a stormwater pond that will be constructed during mining operations.

6.3.3 Degree of Use in Industry

The quality of water flowing passively (gravity flow) through both natural and constructed passive treatment systems is improved by the removal of suspended and dissolved chemicals. The ability of wetlands and other flow-through systems to improve water quality has been studied and documented for many years (Reference (41); Reference (42), Reference (43)). The use of limestone drains, with or without the complement of wetland treatment has been monitored and studied at over 100 locations in West Virginia alone (Reference (44)). Numerous guidance documents for the development of limestone drains, subsurface flow constructed wetlands, and other forms of passive treatment have been published by both State and Federal governments (Reference (45); Reference (46); Reference (36), Reference (43)).

6.3.4 Up Front Preparation

The plan for the West Pit Outlet Structure must account for installation of the passive treatment system in closure. This is accomplished as described in Section 6.2.5.2 of Reference (17) which will be revised to relocate the West Pit Outlet so that there is gravity flow to West Pit Overflow Passive Treatment System.

6.3.5 Timing and Duration of Implementation

The modeled 10th percentile earliest West Pit overflow is 24 years after the completion of mining activities.

The passive treatment system must be functional before the West Pit overflows. A three to five year construction and biological acclimation period is envisioned to allow the system to be fully tested and to allow the wetland vegetation to become well-established before the system is required to be operational. To have a system operating when the West Pit initially overflows between Mine Year 44 and Mine Year 50, construction of the West Pit overflow passive treatment system will start no later than the beginning of Mine Year 39. The passive treatment system will be required to function until constituents have been depleted from the stockpile. The current model shows the time to complete depletion of the sulfur in the waste rock to have a 10th to 90th percentile range of 335 to 385 years. The estimated time (based on extrapolation of the 500 year model) to depletion of soluble metals released from the waste rock but stored in the stockpile as precipitates is more than 1,000 years.

6.3.6 Other Potential Spin-off Impacts

The addition of a multi-stage passive treatment system for the West Pit overflow will have minimal impacts on other portions of the project. The area needed to construct the system is available within the proposed footprint of the Mine Site and will already be disturbed during mining operations, so no additional wetlands impacts will occur.

6.4 Engineering Control Performance Parameters

6.4.1 Description with Basis

6.4.1.1 Limestone Drain

Limestone drains and limestone lined ditches in various configurations have been used to raise the pH of water from a variety of sources. In West Virginia and other eastern states the number of limestone treatment systems currently in use to treat low pH water discharging from abandoned mine lands in in the hundreds (Reference (44)). These systems have been extensively monitored and the general design rule is that a minimum retention time of 15 hours is needed to raise the pH of the influent water by one unit or more. Longer retention times are recommended for waters with very low pH (less than 3) or when large volumes of iron or aluminum hydroxide precipitate are anticipated. Although passivation of the limestone surface was considered a potential limiting condition for these systems at one time, most limestone drains remain effective provided the pore spaces within the drain do not become plugged with precipitate (Reference (44)).

6.4.1.2 Constructed Wetland

A constructed, subsurface flow wetland treatment system at the Savannah River Site was designed to remove copper by the formation of a solid-phase copper-sulfide precipitate that would remain sequestered within the wetland sediments (Reference (47)). The wetland treatment system has a total area of 8.8 acres (including perimeter access areas and multiple locations for hydraulic control) and was designed to treat flows ranging from 0.25 to 2.6 MGD, with an average flow of approximately 1 MGD. The system was installed in 2000 and has been monitored since the spring of 2001.

During the first year of performance monitoring (March 2001 to April 2002) influent copper concentrations ranged from 10 to 47 ug/L. Effluent concentrations ranged from 3 to 11 ug/L with an average effluent copper concentration of 6 ug/L. Additional performance monitoring of the system through 2005 showed that the system performance was maintained with minimal maintenance (Reference (48)). The long-term performance of this full-scale system provides a realistic analog situation that demonstrates the viability of a passive treatment system using constructed wetlands for removal of dissolved metals, particularly copper, to a consistent effluent value that will meet the surface water discharge standards. The wetland at the Savannah River Site is designed to allow the growth of plants to provide all of the substrate necessary to support microbial activity by sulfate reducing bacteria and, ultimately, to sequester copper as copper sulfides, subaqueously, within the wetland soil matrix. Cobalt was not monitored in the Savannah River Site. Nickel was measured, but the influent concentrations were low relative to the predicted concentrations in the West Pit overflow.

Both cobalt and nickel were monitored in the performance of a full-scale wetland treatment system for the treatment of leachate from a coal ash landfill (Reference (49)). This work demonstrated over 96 percent removal of cobalt. Even with relatively a low average influent concentration, cobalt was effectively removed to effluent concentrations consistently less than 2 ug/l in the second year of operation. Nickel removal efficiency on a percentage basis, was relatively low at only 63 percent. However, this was likely due to low influent concentrations, where the maximum nickel concentration was only 55 ug/L. Other wetland systems in Europe have also shown limited nickel removal with low influent concentrations (Reference (50)).

Nickel was present at high concentrations in the leachate from nickel sulfide tailings operation in Norway and was effectively removed using a constructed wetland treatment system at rates up to 99 percent and effluent concentrations below the detection limit of 10 ug/L (Reference (51)). Removal in this system occurred within the anaerobic section of a multi-cell system and was most effective in the summer months.

Removal of lead from wastewater to low concentrations has also been reported in the literature. Hawkins, et al, (Reference (52)) reported removal of lead from an average influent concentration of 10.5 ug/L to an average effluent concentration of 2.2 ug/L using a subsurface flow constructed wetland system.

6.4.1.3 Permeable Sorbtive Barrier (PSB)

Copper and many other metals in solution will have a tendency to preferentially sorb onto solid phase media. Sorption of metals onto solid surfaces has been well-documented in a literature review of numerous sorption tests completed by the U.S. EPA (2005, Reference (53)). In addition, site specific testing with unconsolidated soil from the NorthMet mine site demonstrated that copper sorption was likely near the high end of the reported range for soils (Reference (54)). The basis for the higher than average sorption capacity for copper in site soils may be due to the above average iron content, or other factors that were not evaluated. Given these results, a sorptive barrier for the reduction of copper concentrations in solution is a viable method of achieving the water quality objectives.

Sorption is a finite process for a defined volume of solids. While it appears that site soils may provide an excellent sorptive material, other media specifically designed for metal sorption are available. One such material, which is produced from peat and is produced in Minnesota, is APTsorb. This material is manufactured by American Peat Technology, Inc of Aitkin, MN.

The sorptive capacity of APTsorb for metals, particularly copper, and cobalt has been demonstrated in field testing conducted in cooperation with the Minnesota Department of Natural Resources at the former Soudan Underground Mine, which is now the Soudan Mine State Park (Reference (55)). Copper concentrations were decreased by 90 percent from an average influent concentration of 80 ug/L to an effluent copper concentration of generally less than 8 ug/L. Similarly, cobalt concentrations were also consistently decreased to below the discharge standard of 5 ug/L. Thus, the use of sorptive media is another demonstrated technique to address water quality and reduce concentrations of dissolved copper, cobalt, and other metals in the West Pit overflow in closure.

6.4.1.4 Media Useful Life

A secondary performance parameter associated with passive treatment systems associated with the system is the media useful life. The consumable items include the limestone for the limestone drain and the sorptive media within the PSB.

Assuming that the limestone drain adds 100 mg/L of dissolved calcium carbonate to the water as it flows through the drain, the mass of limestone within the drain system would be reduced by less than one ton per year. Because the drain will contain thousands of tons of limestone rock, the volume of the limestone drain is likely to last for hundreds, if not thousands of years. Although it will not need to be replaced, the limestone may need to be removed and abraded periodically (approximately every 20 years) to improve the reactivity of the surface of the rock materials. Overall, however, it is expected that performance will remain constant as long as the proper hydraulic flow paths are maintained.

The useful life of sorptive media is expected to be 7 or more years and may last indefinitely as metals temporarily bound to organic matter are converted to stable metal sulfide precipitates. Increasing the size of the sorptive barrier, while not improving performance, would likely reduce the potential frequency for replacement of the sorptive media

The constructed wetland treatment system has been sized, based on mass loading and analog data, to provide adequate carbon through annual primary production to promote enough sulfate reduction to adequately remove metals, especially copper. Thus, it will not be necessary to restore the wetland unless the hydraulic capacity of the system degrades over time due to consolidation, metals precipitation, or other factors. In addition, provided the wetland system functions as designed, the sorptive capacity of the downstream PSB should not be exhausted.

6.4.1.5 Model Parameters

Based on literature values described above, Table 6-3 summarizes model parameters that will represent the West Pit Overflow Passive Treatment System.

Table 6-3 West Pit Overflow Passive treatment System Model Parameters

	Effluent Concentration	Basis
Cobalt	2 ug/L	Field analog (Reference (49))
Copper	8 ug/L	Field analog (Reference (48))
Nickel	10 ug/L	Field Analog (Reference (51))
Lead	3.2 ug/L	Field Analog (Reference ((52))

6.4.2 Maintenance Program

The planned passive treatment system requires a minimum amount of periodic maintenance to remain effective. The periodic maintenance consists of removal and abrading of limestone every 20 years and replacement of sorptive media as determined by media useful life (Section 6.4.1.4). The expected useful life of the sorptive media is expected to be a minimum of 7 years. The full depletion of constituents from the Category 1 Waste Rock Stockpile, East Pit Wall Virginia Formation and West Pit Wall Ore Grade Material is expected to take more than 1,000 years which would result in about 50 limestone removal/abradings and about 150 sorptive media replacements.

6.4.3 Modeling of Engineering Controls

The components of the West Pit overflow passive treatment system will be incorporated into the Mine Site water model. In general, these components will have the following characteristics:

- The design maximum discharge volume through the overflow passive treatment system will be 6.35 cfs, and will occur over a period of two months.
- The passive treatment system will be incorporated into the GoldSim model in two steps.
  - (Limestone Drain) - The pH of the overflow will be set to a value of 7.5 while maintaining all other model constraints from the West Pit. Calcium and carbonate (alkalinity) mass will be added to the water based on the change in pH required (from assumed West Pit lake pH of 7.0 to 7.5 to a fixed value of 7.5). No other mass will be added, however, existing load will re-equilibrate with pH-based concentration caps already defined for use in the West Pit modeling.
  - (Constructed Wetland and PSB) The effluent concentrations will be set to the design values listed in Table 6-3.
- The performance of the overflow passive treatment system will not change over time because any maintenance or upgrades necessary to maintain performance would be completed, when discharge from the system is not occurring.

Effluent concentrations are used in the modeling of this treatment unit because the performance of the system is controlled by thermodynamic properties of the constituents being treated (solubility) and thus are independent of the influent concentration. In addition, the relatively low influent concentrations to the West Pit overflow treatment system would require removals on a percentage basis that are would generally be less than what has been observed in many of the published reports where higher influent concentrations were treated. In this case, using a percentage removal would likely result in effluent concentrations that are lower than necessary and potentially lower than typical detection limits for these parameters.

6.4.4 Impact on Compliance

Table 6-4 shows he modeled measure of compliance (number of P90 results not exceeding the water quality standard / number of P90 results) for resource objectives for constituents in the West Pit overflow that do not meet resource objectives with and without the passive treatment system with the engineering controls in Sections 2.0 through 5.0 implemented.

Table 6-4 West Pit Overflow Passive Treatment System Impact on West Pit Overflow

	Measure of Compliance	
Constituent	**No Passive Treatment System**	**With Passive Treatment System**
Co	0%	100%
Cu	0%	100%
Ni	0%	100%
Pb	39%	100%

Note: All Mine Site modeling assumes that all Plant Site engineering controls are in place, including water transferred to the West Pit from the Plant Site.

6.5 Anticipated Project Monitoring

The Project includes a comprehensive water quality and quantity monitoring program that will be finalized in permitting. The program includes compliance monitoring for the West Pit overflow. See Section 5 of Reference (1) for details.

6.5.1 Special Performance Monitoring

The planned project monitoring will include flow and water quality from the West Pit. In order to measure passive treatment system performance, water into and out of the passive treatment system will be sampled.

6.5.2 Test Projects

A test project will be developed [detailed design in permitting and included in this document] to evaluate the effectiveness of the planned West Pit overflow passive treatment system. A pilot scale passive treatment system of the planned design will be constructed at the Mine Site during the post closure (West Pit flooding) phase of the project. A portion of the actual West Pit water that will be pumped to the WWTF during closure would be diverted to the overflow passive treatment pilot unit to evaluate and optimize system performance well before the full-scale system is designed and placed into operation.

6.5.3 Reporting and Model Update

The Project includes a comprehensive water quality and quantity reporting program that will be finalized in permitting. The program includes annual comparison of actual monitoring to modeled results for the West Pit overflow. This comparison and results from Special Performance Monitoring and Test Projects above will be used to refine the model. See Section 6 of Reference (1) for details.

6.5.4 Adaptive Management and Contingency Mitigation

The Project includes a comprehensive water quality and quantity reporting program that will be finalized in permitting. The program includes adaptive management for the West Pit water quality. See Section 6.5 and 6.6 of Reference (1) for details.

6.6 Modified Design

The annual model update may indicate a need to change the design of the passive treatment system. The passive treatment system design can be modified up to the point of implementation (Section 6.3.5). The current version of this document will determine the design to be implemented.

6.6.1 Circumstances Triggering Modification

Two circumstances could trigger a design modification:

1. Demonstration by actual field testing or analog sites that a modified passive treatment system design will achieve the required Effluent Concentrations.

2. Demonstration by actual field monitoring of the Project and model updating that the required influent concentration has changed and that a modified design can achieve the required Effluent Concentrations. The required Effluent Concentrations could change for various reasons, including:

    a. modeled performance of other engineering controls (Sections 2.0 through 5.0 could change

    b. modeled constituent load from backfilled Category 2, 3 and 4 waste rock, pit walls or Category 1 Waste Rock Stockpile could change

    c. modeled groundwater inflow or surface runoff into the pits could change

6.6.2 Options with Increased Performance

The design of the passive treatment system can be adjusted to increase performance if required. Increased performance could include the following items, in order of increased performance provided:

- Longer retention times would allow more time for the flow to react with the limestone, sulfate reducing bacteria within the wetland, or the sorptive media within the sorptive barrier.

- Different media that could improve the transfer of alkalinity into the water or improve the removal of copper and other dissolved constituents from the water.

6.6.3 Options with Decreased Performance

The design of the passive treatment system can be adjusted to decrease performance if required. Decreased performance could include the following items, in order of decreased performance provided:

- Shorter retention times would allow less time for the water to react with the limestone, sulfate reducing bacteria within the wetland, or the sorptive media within the sorptive barrier.

- Partial or complete bypass: A portion of the West Pit overflow could be routed around the passive treatment system and blended with the treatment system effluent.

- Alternative media: different media with a longer operating life, but potentially less affinity for metal sorption could be used to decrease the performance of the system, while also decreasing the potential replacement frequency.

6.7 Financial Assurance

The cost for implementation of the passive treatment system including test project (Section 6.5.2), performance monitoring (Section 6.5.1), periodic maintenance and media replacement will be included in the Contingency Reclamation Estimate that will be the basis for financial assurance. The estimate will be updated annually based on the liability at the end of the following year. See Reference (1), Section 7.4 for details.

7.0 Flotation Tailings Basin (FTB) Adaptive Water Management

7.1 Project Feature

The FTB is a permanent mine waste disposal facility and will contain about 228 million tons of low sulfur (bulk tailings most representative of final plant design – 3 samples - maximum of 0.13%; average 0.11%) tailings that is not projected to generate acid but are projected to release heavy metals at concentrations in exceedance of applicable water quality standards. The FTB is constructed on top of a legacy taconite tailings basin. The FTB covers about half of the legacy facility (legacy Cells 1E and 2E). The FTB does not cover legacy Cell 2W.

7.2 Resource Objectives

The resource objectives are to:

- meet the applicable surface water standards (Reference (56), Tables 1-2 and 1-3) in three (Trimble Creek, Mud Lake Creek and Unnamed Creek) Embarrass River tributaries at their headwaters near the FTB (at this time, the 90th percentile probabilistic model result being below the applicable standard is assumed to meet the objectives),

- meet the applicable groundwater standards (Reference (56), Table 1-4) at the property boundary (at this time, the 90th percentile probabilistic model result being below the applicable standard is assumed to meet the objectives), and

- meet MPCA criteria with regard to sulfate at the three tributary headwaters (no increase in sulfate load relative to the modeled no action condition) and PM-13 (no increase in concentration relative to the modeled no action condition)

Note that FTB Adaptive Water Management alone cannot achieve the resource objectives. The engineering controls described in Section 8.0 is also required for reduction of groundwater seepage and the engineering control described in Section 9.0 is required for final passive treatment of some constituents (B, Co, Cu, and Ni).

7.3 Planned Engineering Control

FTB Adaptive Water Management consists of the Groundwater Seepage Management System and the FTB to Mine Site Water Transfer System. Note that there are other water management systems that are not part of adaptive management. These are described in Section 2 of Reference (2).

The Groundwater Seepage Management System provides the ability to collect water seeping from the FTB via shallow groundwater flow. During operations, this water will be returned into the FTB pond for reuse to the extent possible with any excess treated via the WWTP and discharged. During closure, the Groundwater Seepage Management System will continue to operate until FTB cover systems have become effective and FTB hydrology has stabilized. A preliminary profile along the containment system alignment is shown in Figure 7-1 and a preliminary cross-section of the system is shown in Figure 7-2.

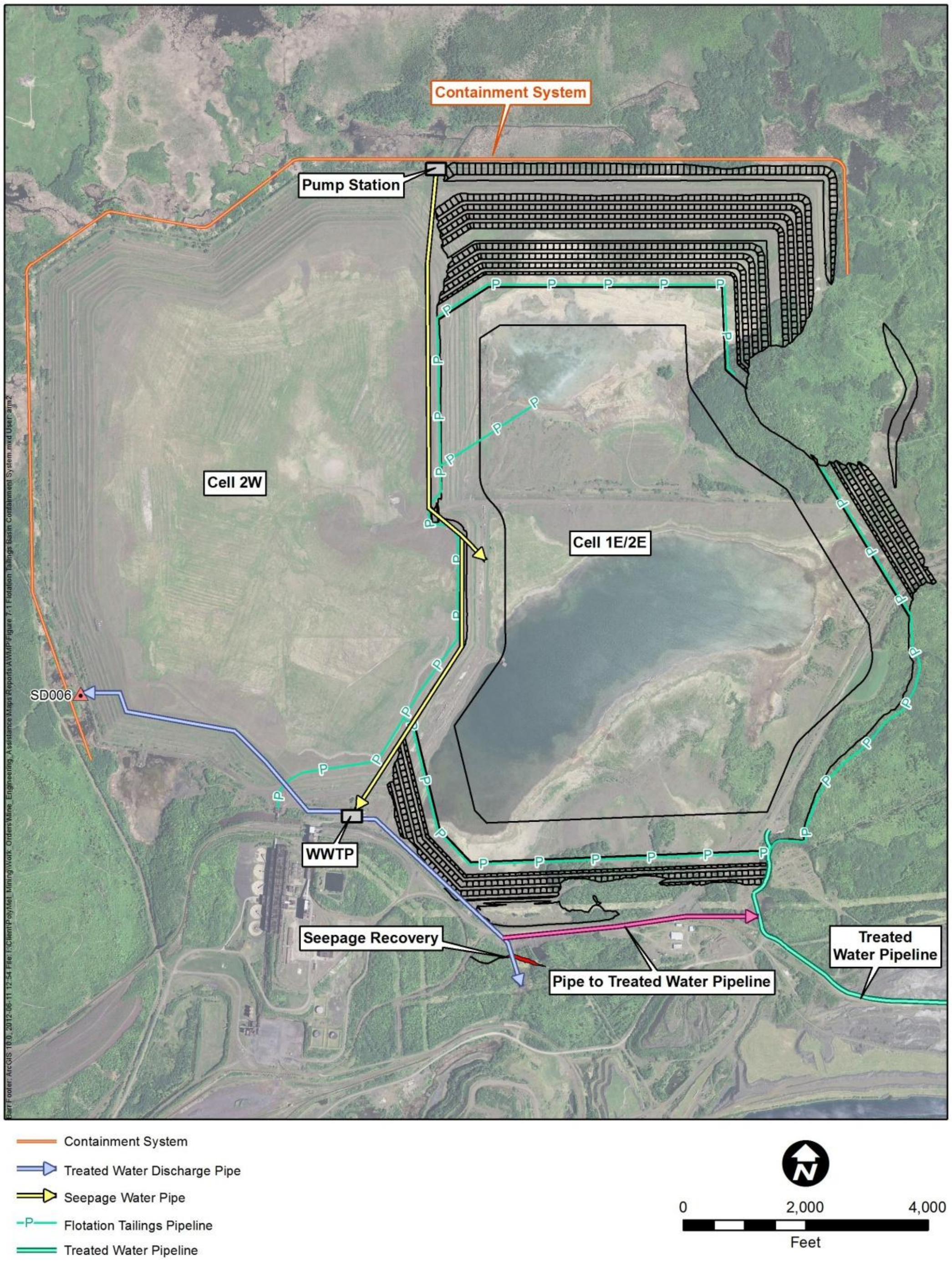

Figure 7-1 Flotation Tailings Basis Containment System

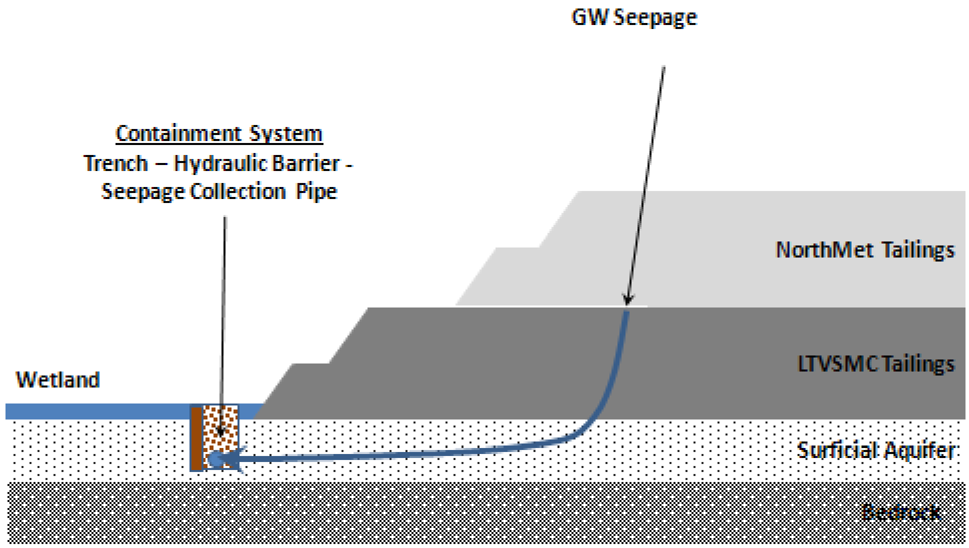

Figure 7-2 Cross Section - Containment System

The FTB to Mine Site Water Transfer System provides the ability to transfer water from the FTB to the Mine Site. The system will be utilized in closure to pump water to the Mine Site during the first 14 years of closure while the WWTP is being used to remove built up constituents from the FTB pond water and the FTB is being reclaimed. Once the FTB is reclaimed, any excess water in the FTB pond (only source is precipitation) will overflow by gravity as stormwater.

7.3.1 Purpose

The purpose of the FTB Adaptive Water Management is to control the amount of constituent load escaping from the FTB by controlling the amount of water escaping from the FTB.

7.3.2 Design

The Groundwater Seepage Management System consists of a containment system, pump system and pipelines and the WWTP.

The Water Transfer System uses the pumps of the Groundwater Seepage Management System to pump water from the FTB to the Mine Site via the Treated Water Pipeline used to transport water from the Mine Site to the FTB during operations.

7.3.2.1 Containment System

A containment system [similar to the Category 1 Waste Rock Stockpile Groundwater Containment System] will be installed near the toe of the north and west Tailings Basin dams to intercept at least 96% of the groundwater seepage from the FTB. The capture of groundwater seepage to the south of the FTB is accomplished by the surface seepage management system proposed for the FTB (Reference (2)). High bedrock along the east side of the FTB limits groundwater seepage in this direction making it unnecessary to extend the containment system to this area. The interception of 96% of groundwater seepage is a modeling assumption that will be confirmed or adjusted as needed once final water quality performance requirements and monitoring locations have been established by the MPCA.

The containment system consists of a trench excavated into existing surficial deposits and subsequently backfilled with granular drainage material after installation of a seepage collection pipe and hydraulic barrier on the downstream (away from the FTB) side of the trench. During final design and construction the trench, alignment and depth will be optimized to achieve the desired performance effectiveness. The seepage collection rate will be managed by striving to locate the trench where the thickness of the surficial deposits above bedrock is thinnest (where bedrock is shallowest), thereby reducing the amount of seepage drawn in from the downstream (i.e., non FTB) side of the trench. While the trench alignment has not been finalized, it is anticipated that the thickness of the surficial deposits could be up to 40 ft. The modeling described in Section 7.4.3 demonstrates that the required seepage collection efficiency can be achieved under these conditions with this containment system design.

The granular drainage material component of the trench will also function as a drain to capture water discharging to the wetland area upgradient of the containment system. During final design, if it is determined that additional flow capacity is required to capture this component of flow, then similar to the system proposed for the Category 1 Waste Rock Stockpile Groundwater Containment System, vertical risers will be added to the containment system collection pipe to provide a more efficient method of collecting the water discharging to the wetland area upgradient of the containment system.

7.3.2.2 Pump System and Pipelines

Water in the containment system will be collected in sumps. Water from all of the collection sumps will be routed to lift sumps that will serve as the collection points for all of the seepage. Pumps installed in the lift sumps will be used to convey the collected seepage through pipelines to the FTB Pond or WWTP, depending on operational requirements. To implement FTB to Mine Site Water Transfer the lift sump pumps will be connected to the Treated Water Pipeline that runs between the FTB and the Mine Site WWTF. All pumps in the Groundwater Seepage Management System will be operated using level sensors so that a desired water level is maintained in the sumps.

7.3.2.3 Waste Water Treatment Plant (WWTP)

Water collected by the Groundwater Seepage Management System in excess of that which can be retained in the FTB pond will be treated at the WWTP and discharged. The purpose of water treatment is to meet applicable water discharge limits including 10 mg/L sulfate.

The WWTP will contain the following unit operations:

- Chemical addition and filtration, and
- Membrane separation using reverse osmosis (RO).

The groundwater will have high concentrations of dissolved iron and manganese, which are redox sensitive and will likely begin to precipitate during the extraction process. At the WWTP additional chemicals will be added to complete the precipitation process and then the precipitated solids will be removed by filtration. The remaining dissolved constituents, particularly sulfate, will be removed using the membrane separation processes. By applying pressure across the membrane of the RO system, the dissolved constituents will be concentrated in a portion of the stream (retentate) while producing a clean stream (permeate) that will meet the discharge limits.

The flow to the WWTP will vary significantly over the life of the Project. To address this variability, the WWTP will be designed in a modular format that can be expanded. The initial design will be capable of treating the anticipated flows in the first nine years. The effluent (permeate) from the WWTP will be pumped to a discharge at SD026 or SD006. The retentate will be delivered to the Mine Site Wastewater Treatment Facility (WWTF) and will be treated in the chemical precipitation unit operations.

7.3.3 Degree of Use in Industry

Containment systems such as the one planned are commonly used at facilities where there is a need to manage groundwater flow and constituent transport via groundwater, such as at unlined landfills, tailings basins, and paper sludge disposal facilities. The use of groundwater seepage containment pipes and trenches is often combined with slurry wall technology (bentonite slurry filled trench); the choice between use of a slurry wall, a geomembrane, a natural clay barrier or other type of hydraulic barrier is made on a project-specific basis, weighing factors such as characteristics of the surficial deposits to be excavated, rate of construction desired, availability of construction materials, and other factors.

The treatment technologies planned for the WWTP are in common use to provide industrial process water for a wide range of industrial activities such as minerals processing, power production, and municipal drinking water supply. Chemical addition and filtration and RO are well developed water treatment technologies that have seen use world-wide for many years.

7.3.4 Up Front Preparation

None required.

7.3.5 Timing and Duration of Implementation

The Groundwater Seepage Management System must be functional for its initial capacity when NorthMet tailings are first placed in the FTB. Incremental capacity of the WWTP must be added as shown in Figure 7-3.

The Groundwater Seepage Management System will be required to function until the seepage from the FTB has stabilized following FTB closure activities. The current model shows this time to have a 10th to 90th percentile range of 10 to 15 years. The FTB to Mine Site Water Transfer must be functional starting at closure and operate for fourteen years. Fourteen years is the approximate amount of time that FTB water can be sent to the Mine Site without negatively affecting the ability of the West Pit water quality to meet applicable standards at the point of overflow.

The Groundwater Seepage Management System has three phases (see Figure 7-3):

- Operations – water collected in Containment System pumped to FTB pond with any excess treated by WWTP and discharged

- Reclamation – water collected in Containment System pumped West Pit - WWTP used to clean up the FTB pond

- Stabilizing – water collected in Containment System treated by WWTP and discharged to FTB pond – excess overflows pond

When the operation of the Groundwater Seepage Management System is discontinued, the resource objectives will be achieved by the FTB Groundwater Seepage Passive Treatment System described in Section 9. The timing of this change will be determined by post closure monitoring.

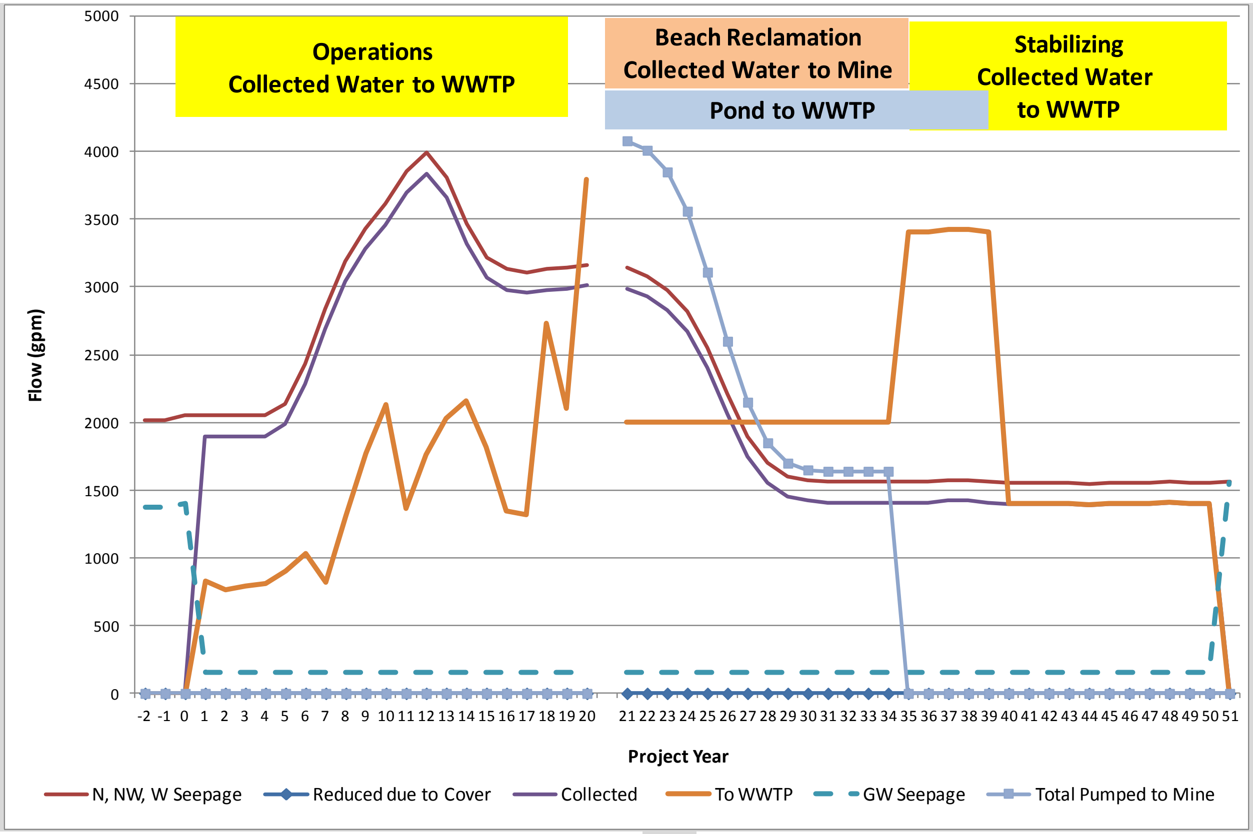

Figure 7-3 Timeline of FTB Water Management

7.3.6 Other Potential Spin-Off Impacts

Anticipated impacts associated with installation and operation of the Groundwater Seepage Management System are a need for additional wetland mitigation because of impacts in the zone adjacent the Tailings Basin toe-of-slope that will be affected by system construction (ground disturbance) and system operation (change in hydrology). Because of the reduction of seepage to the wetlands outside of the containment system near the FTB, there will be an indirect impact to those wetlands.

Water treatment and handling systems will require sizing to accommodate the flow of water anticipated to be collected by the Groundwater Seepage Management System. Increases in facility sizing and flow rate will have some impacts on the amount of treatment plant solids requiring disposal.

7.4 Engineering Control Performance Parameters

Because the containment system is designed so that leakage through the system is returned into the FTB, at least 96% of the seepage in the areas covered by the system is planned to be intercepted. The constituent removal at the WWTP is assumed to be as designed.

7.4.1 Description with Basis

The hydraulic barrier and seepage collection pipe portions of the Groundwater Seepage Management System will create an inward hydraulic gradient toward the collection drain resulting in higher hydraulic heads on both the FTB side of the containment system and the exterior/wetland side of the containment system, with lower hydraulic heads within the containment system, where the drain is utilized to lower the water level. Because groundwater and any contained constituents move from areas of high hydraulic head to areas of lower hydraulic head, the containment system will capture groundwater that may otherwise leave the FTB. The establishment of an inward hydraulic gradient from the wetland side of the barrier in towards the containment system will minimize the potential for FTB seepage to reach the wetlands, but does allow for the potential for wetland water to be captured. This potential for the collection of wetland water is the reason for the installation of the hydraulic barrier in conjunction with the seepage collection pipe, which should limit this potential.

7.4.2 Maintenance Program

The planned containment system requires periodic maintenance to remain effective. The periodic maintenance consists of inspection via video camera of the drain pipe to make sure it is not blocked by sediments or collapsed. If sediments are observed and are determined to be inhibiting system performance, they will be cleaned out by flushing. If collapse is observed, the collapsed section will be repaired. The periodic inspection will be every 5 years unless monitoring of the amount of water collected by the containment system indicates there has been an unusual change in flow that could be caused by collapse.

7.4.3 Modeling of Engineering Controls

As supported by the following analysis and the fact that the containment system can be designed to collect the surface water upgradient of the system, the containment system will be modeled as collecting all groundwater seepage leaving the Tailings Basin that is in excess of the local surficial aquifer capacity (i.e., all seepage above approximately 150 gpm).

The effectiveness of the containment system portion of the Groundwater Seepage Management System at the Tailings Basin was evaluated using a MODFLOW model. A conceptual representation of the hydrogeology along a typical groundwater flow path is shown on Figure 7-4. Water from the Tailings Basin seeps downward to the native unconsolidated deposits located beneath the tailings. The unconsolidated deposits are underlain by crystalline bedrock having low permeability. Groundwater within the native deposits flows from the Tailings Basin toward the Embarrass River and its tributaries. Once the seepage has passed from the Tailings Basin, some portion discharges to the wetland areas adjacent to the dam and some portion remains in the unconsolidated deposits.

The model was designed to evaluate how much of the seepage will be captured by the containment system trench, how much will discharge to the wetland deposits upgradient of the trench, and how much will pass beneath the trench.

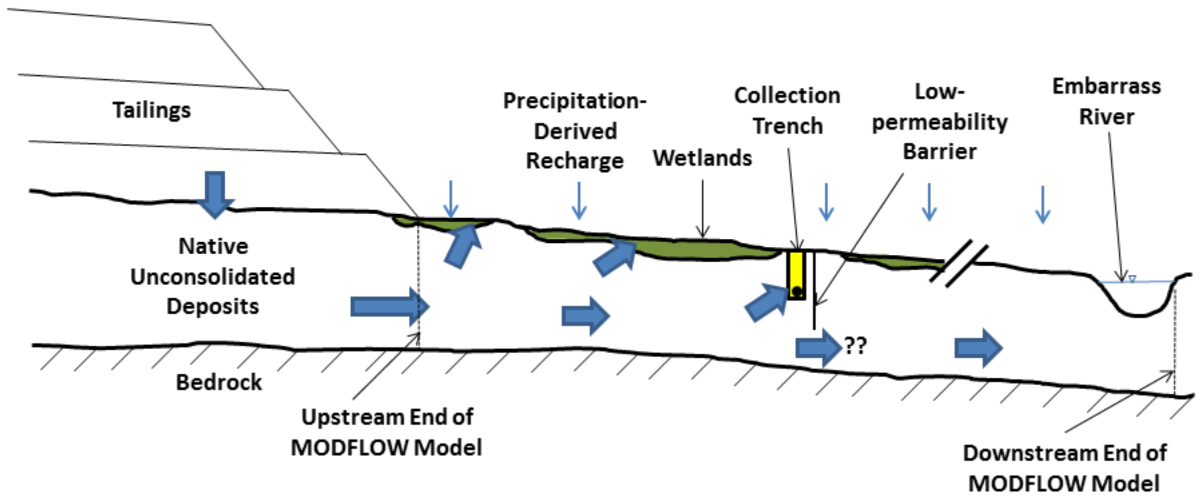

Figure 7-4 Conceptual Representation of Hydrogeology Along Typical Groundwater Flow Path

A schematic representation of the MODFLOW model is shown on Figure 7-5. The primary groundwater sources considered in the MODLFOW model were seepage from the Tailings Basin via specified flux cells located at the upstream end of the model and recharge applied to the top of the model. River cells were used to represent wetland areas and were assigned a control elevation equal to the ground surface elevation. If the head in the aquifer was higher than the river cell control elevation, water was removed from the aquifer. In contrast, if the head in the aquifer was lower than the river cell control elevation, the river cell would contribute water to the aquifer. In the area, wetland areas are generally expected to act as discharge areas for groundwater, especially near the toe of the Tailings Basin, and model results were consistent with this conceptual model (i.e., river cells did not add water to the model). The specified flux rates at the upstream end of the model were assigned based on seepage estimates from the three-dimensional (3D) MODFLOW model of the Tailings Basin area (Reference (57)). Two scenarios were evaluated – one with a higher seepage rate representative of conditions during operations and one with a lower seepage rate representative of post-closure conditions. Recharge was assigned using the calibrated value from the 3D MODFLOW model (Reference (57)). Sinks in the model (i.e., locations where water can be removed from the system) were the trench seepage collection pipe, the river cells representing wetlands, and the specified head cells representing the Embarrass River. Consistent with previous modeling (Reference (58); Reference (57)), the underlying bedrock was assumed to be impermeable and the bottom of the model was a no-flow boundary.

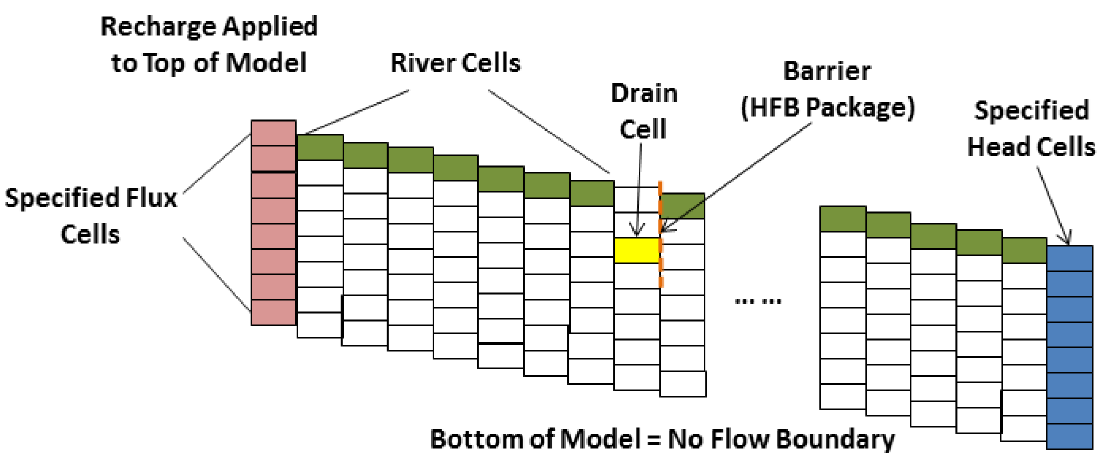

Figure 7-5 Schematic Representation of the MODFLOW Model

The model grid has a single 1-meter-wide row and 500 columns, each 10 meters long. The overall length of the model is representative of the average distance between the Tailings Basin and the Embarrass River. The drain cell is located 200 meters from the upstream end of the model. Average ground surface slope and hydraulic gradient from previous modeling efforts (Reference (58), Reference (57)) were used to define the model layer geometry. The thickness of the model was 8 meters, a representative average of the thickness of the unconsolidated deposits along the anticipated containment system alignment. Key model parameter values are summarized in Table 7-1.

Table 7-1 Key Tailings Basin MODFLOW Model Parameter Values

Parameter	Value	Units	Data Source
Recharge	6	in/yr	Calibrated 3D MODFLOW model (Reference (57))
Seepage from Tailings Basin – Operations Conditions	0.13	gpm/linear foot of dam	From 3D MODFLOW model seepage estimates
Seepage from Tailings Basin – Closure Conditions	0.06	gpm/linear foot of dam	From 3D MODFLOW model seepage estimates
Horizontal Hydraulic conductivity	4.6×10^{-3}	cm/s	Representative average value based on single-well aquifer tests near Tailings Basin perimeter (Reference (59))
Horizontal Hydraulic conductivity	4	m/d	
Ratio of vertical to horizontal hydraulic conductivity	0.5	unitless	Assumed value

Parameter	Value	Units	Data Source
Hydraulic barrier depth	13.1	ft	Assumed value
Aquifer thickness	26.3	ft	Representative average value based on depth to bedrock information along containment system alignment
Drain stage below land surface	8.2	ft	Assumed value

Simulations were run using a higher seepage rate representative of conditions during operations and a lower rate representative of conditions during closure. For each of these seepage rates, simulations were run with the depth of the hydraulic barrier ranging from 4 meters to 7 meters. The model results indicated that, regardless of the seepage rate or the barrier depth, all of the seepage that enters the upstream end of the model was either captured by the containment system trench or discharged to the wetlands between the Tailings Basin and the trench. No seepage that originates from the Tailings Basin passed beneath the trench. Table 7-2 and Table 7-3 summarize the percentage of the seepage captured by the wetlands upgradient of the trench and the trench. During operations, a larger percentage of the seepage discharges to the wetlands upgradient of the trench than to the trench. A larger percentage of the seepage is captured by trench during closure.

Table 7-2 Percentage of Tailings Basin Seepage to Upgradient Wetlands and Trench – Operations

Barrier Depth (m)	% Seepage Upwelling Prior to Trench	% Seepage Collected in Trench
4	75	25
5	72	28
6	61	39
7	54	46

Table 7-3 Percentage of Tailings Basin Seepage to Upgradient Wetlands and Trench – Closure

Barrier Depth (m)	% Seepage Upwelling Prior to Trench	% Seepage Collected in Trench
4	49	51

5	34	66
6	19	81
7	4	96

The model was also used to evaluate expected flow rates to the containment system trench and upgradient wetland areas during operations and closure with the depth of the hydraulic barrier ranging from 4 to 7 meters. The estimated flows to the trench per linear foot of trench for operations and closure range from approximately 0.04 gpm/ft to 0.07 gpm/ft. Assuming a 24,000 ft long containment system, this equates to 1,000 gpm to 1,800 gpm. These flow rates reflect both Tailings Basin derived seepage and water that enters the aquifer via precipitation-derived recharge and ultimately reach the trench. A portion of the water that reaches the trench originates in areas between the containment system and the Embarrass River because the trench creates a cone of depression that extends towards the Embarrass River. In addition to the groundwater seepage that discharges to the trench itself, the model estimates that approximately 70 gpm to 2,300 gpm discharges to the wetlands areas located between the toe of the Tailings Basin and the trench. This range of discharge rates reflects model results using the operations and closure flow conditions and hydraulic barrier depths ranging from 4 to 7 meters. As shown in Table 7-2 and Table 7-3 above, a portion of the water discharging to the upgradient wetlands areas is Tailings Basin derived seepage.

As indicated by model results presented in Tables 7-2 and 7-3, the desired prevention of seepage downgradient of the containment system trench can be achieved by a number of containment system barrier depths. To minimize impacts on wetlands and to minimize overall system costs while still achieving system performance objectives (including tailings basin slope stability), it is anticipated that preference will be given to shallower rather than greater trench depth. Further, because making the collection trench and hydraulic barrier deeper and extending it to bedrock would provide no apparent performance benefit over the shallower options modeled, such an approach is not under consideration and is not warranted. Final barrier depth will be selected as part of final design of the containment system and will be adjusted in the field during construction in response to in-field conditions that cannot be determined or fully anticipated except as construction proceeds.

7.4.4 Impact on Compliance

Table 7-4 through Table 7-5 show the modeled measure of compliance (number of P90 results not exceeding the water quality standard / number of P90 results) for resource objectives for constituents in the surface water (tributaries) and groundwater and MPCA criteria that do not meet resource objectives with and without the adaptive water management.

Table 7-4 FTB Adaptive Water Management Impact on Surface Water

Measure of Compliance								
	No Water Management				With Water Management			
Constituent	MLC-3	TC-1	UC-1	PM-13	MLC-3	TC-1	UC-1	PM-13
Al	10.5%	68.0%	99.5%	0.0%	5.0%	73.0%	79.5%	0.0%
B	100%	100%	100%	100%	100%	100%	27.5%	100%
Co	0.0%	0.0%	93.5%	95.0%	20.0%	20.0%	87.5%	100%
Cu	0.0%	1.5%	91.0%	3.5%	20.0%	20.0%	100%	20.0%
Ni	57.0%	84.0%	100%	100%	83.0%	100%	100%	100%
Pb	93.0%	100%	100%	100%	100%	87.0%	85.5%	100%

Table 7-5 FTB Adaptive Water Management Impact on MPCA Criteria

Measure of Compliance								
	No Water Management				With Water Management			
Constituent	MLC-2	PM-19	PM-11	PM-13	MLC-2	PM-19	PM-11	PM-13
SO4	100%	100%	100%	98.0%	74.5%	100%	100%	100%

7.5 Anticipated Project Monitoring

The Project includes a comprehensive water quality and quantity monitoring program that will be finalized in permitting. The program includes compliance monitoring for the tributaries, PM13 and groundwater at the property boundary as well as general performance monitoring for the Groundwater Seepage Management System (quantity and quality of the water collected by the containment system, water into the WWTP and water out of the WWTP). See Section 5 of Reference (2) for details.

7.5.1 Special Performance Monitoring

There will be no additional performance monitoring.

7.5.2 Test Projects

There are no test projects planned.

7.5.3 Reporting and Model Update

The Project includes a comprehensive water quality and quantity reporting program that will be finalized in permitting. The program includes annual comparison of actual monitoring to modeled results for the water collected by the containment system, the tributaries and PM13. This comparison will be used to refine the model. See Section 6 of Reference (2) for details.

7.5.4 Adaptive Management and Contingency Mitigation

The Project includes a comprehensive water quality and quantity reporting program that will be finalized in permitting. The program includes adaptive management for the FTB pond water quality and ground/surface water down gradient from the FTB. See Section 6.5 and 6.6 of Reference (2) for details.

7.6 Modified Design

The annual model update may indicate a need to change the design of FTB Adaptive Water Management. The system design can be modified up to the point of implementation (Section 7.3.5). The current version of this document will determine the design to be implemented.

7.6.1 Circumstances Triggering Design Change

Two circumstances could trigger a design modification:

1. The development of new construction materials or techniques that would achieve the required amount of water to be collected.
2. Demonstration by actual field monitoring of the Project and model updating that the required amount of water to be collected has changed and that a modified design can achieve that amount. The required amount could change for various reasons:
    a. modeled performance of other adaptive engineering controls (Sections 8.0 to 9.0) could change
    b. modeled constituent load from FTB could change

7.6.2 Options with Increased Performance

The WWTP could be operated for longer time or at higher rates if the FTB pond requires more cleanup

Excess WWTP capacity could be used to clean up the FTB pond during the Operations phase or to treat some of the water being pumped to the West Pit in the Reclamation phase.

Although system design is planned to achieve at least 96% seepage capture, there are a number of methods by which system performance could be increased:

- The containment system could be supplemented with a number of groundwater recovery wells to improve performance along select locations of the system.
- The water elevation within the containment system could be maintained at a lower operating level to achieve a steeper inward groundwater flow gradient toward the system.

7.6.3 Options with Decreased Performance

The WWTP could be operated for a shorter time or at lower rates if the FTB pond requires less cleanup.

The system modifications that could be made to achieve decreased performance levels include:

- The containment system could be reduced to cover less of the combined FTB/legacy facility.
- The water elevation within the system could be maintained at a higher operating level to achieve a flatter inward groundwater flow gradient toward the system.

7.7 Financial Assurance

The cost for implementation of FTB Adaptive Water Management including periodic maintenance will be included in the Contingency Reclamation Estimate that will be the basis for financial assurance. The estimate will be updated annually based on the liability at the end of the following year. See Reference (2), Section 7.4 for details.

8.0 Flotation Tailings Basin (FTB) Cell 1E/2E Enhanced Cover System

8.1 Project Feature

The reclamation plan for the FTB originally included a bentonite augmented cover system designed to provide an oxygen barrier around the tailings in order to reduce oxidation and resultant production of chemical constituents. This cover is described in Reference (5) Section 7.2. This cover system was designed such that the oxygen barrier was maintained and a permanent pond with no routine overflow was maintained.

8.2 Resource Objectives

The resource objectives are to:

- meet the applicable surface water standards (Reference (56), Tables 1-2 and 1-3) in three (Trimble Creek, Mud Lake Creek and Unnamed Creek) Embarrass River tributaries at their headwaters near the FTB. At this time, the 90th percentile probabilistic model result being below the applicable standard is assumed to meet the objectives,

- meet the applicable groundwater standards (Reference (56), Tables 1-4) at the property boundary. At this time, the 90th percentile probabilistic model result being below the applicable standard is assumed to meet the objectives,

- meet MPCA criteria with regard to sulfate at the three tributary headwaters (no increase in sulfate load relative to the modeled no action condition) and PM13 (no increase in concentration relative to the modeled no action condition)

Note that the Cell 1E/2E Enhanced Cover System alone cannot achieve the objectives. The engineering controls described in Section 7.0 are also required for constituent control (BAl, B, Co, Cu, Ni, and PbPb) and the engineering control described in Section 9.0 is required for final passive treatment of some constituents (BB, Co, Cu, Ni, and PbPb).

8.3 Planned Engineering Control

8.3.1 Purpose

The purpose of the FTB Cell 1E/2E Enhanced Cover System is to increase the performance of the bentonite augmented cover system in the FTB pond area to reduce the load in the water seeping from the FTB.

The current model assumes an FTB pond area cover system with mean percolation rate of 6.5 in/yr. Actual monitoring of Project water quality parameters and annual updating of the model will determine if a different percolation rate limit is required.

8.3.2 Design

The FTB final reclamation plan includes bentonite augmentation of the pond area bottom to reduce percolation to a sufficient degree to maintain desired pond water elevations at closure, thereby acting as an oxygen barrier above the tailings in order to reduce oxidation and resultant production of chemical constituents. In the pond area, bentonite will be placed by broadcasting bentonite pellets or granules.

In pond areas bentonite addition on a dry weight basis will be as needed to control seepage from the basin as dictated by water quality performance requirements. Because bentonite addition in the pond area is by broadcasting rather than by mixing with a specified thickness of tailings, the percent addition by dry weight cannot be pre-determined. Rather, final quantity of bentonite added to the pond area will be determined by in-laboratory hydraulic conductivity testing (i.e., testing of bentonite application rate versus percolation rate, compared to modeled percolation rate required to sustain the pond) performed near the time of construction to determine what application rate will yield the required resistance to percolation from the pond,. Section 7.2 of Reference (5) provides further details on the methods and equipment proposed to accomplish the bentonite augmentation of the tailings.

The design described above will be enhanced as needed by the addition of bentonite to reduce percolation to achieve the required performance levels.

8.3.3 Degree of Use in Industry

Bentonite is a naturally occurring clay (usually forms from weathering of volcanic ash) consisting mostly of a clay mineral called montmorillonite. Montmorillonite is a very soft phyllosilicate group of minerals that typically form in microscopic crystals, forming a clay. Montmorillonite is a 2:1 clay, meaning that it has 2 tetrahedral sheets sandwiching a central octahedral sheet. The particles are plate-shaped with an average diameter of approximately one micrometer. The water content of montmorillonite is variable and it increases greatly in volume when it absorbs water. Chemically it is hydrated sodium calcium aluminum magnesium silicate hydroxide $(Na,Ca)_{0.33}(Al,Mg)_2(Si_4O_{10})(OH)_2 \cdot nH_2O$. Potassium, iron, and other cations are common substitutes; the exact ratio of cations varies with source.

Small amounts of bentonite were first commercially mined in the 1880's and its uses have expanded since then. For industrial purposes, two main classes of bentonite exist: sodium and calcium bentonite. Bentonite is used in the geotechnical exploration and oil drilling industry as a component of drilling mud, making the mud slurry viscous which helps in keeping the drill bit cool and removing drilled solids. It is also used as a soil additive to hold soil water in drought prone soils, in the construction of earthen dams and levees to prevent the leakage of fluids, as an additive to water to create a liquid slurry as part of groundwater flow cutoff walls and to facilitate construction within excavations below groundwater elevations, and as a component of foundry sand and as a desiccant to remove moisture from air and gases. Bentonite is also used as the primary hydraulic barrier in a manufactured clay liner product called geosynthetic clay liner

(GCL) and as an admixture with soil to produce a constructed hydraulic barrier for pond liners, in earthen dams and as waste containment cover systems.

Bentonite amended soil cover systems have been used for many years in a wide variety of applications including closure of municipal and industrial solid waste disposal facilities, mine tailings facilities and for related components such as for groundwater flow cutoff walls and as hydraulic barriers in earthen dams.

Use of bentonite amended soils is typically dictated by the lack of other suitable nearby construction materials such as a high quality local clay source, by limitations in construction season and time available for placement of other natural soil types, and by the need for hydraulic barrier of lower hydraulic conductivity than might be available from other clay sources.

CETCO (a multinational manufacturer and distributor of powdered and granulated bentonite and manufactured geosynthetic clay liners) is one of several companies with a long history of providing bentonite-based products and associated research and specifications for use by design engineers, facility owners and construction contractors involved in the design and construction of bentonite-amended soils for hydraulic barriers and other applications. Wyo-Ben is another manufacturer and worldwide distributer of bentonite products used in the construction industry for projects such as bentonite amended cover systems.

Long term performance of the bentonite amended beaches is not anticipated to be overly sensitive to root invasion from establishment of vegetation on beaches nor to impacts from burrowing animals. The 18-inches of cover over the bentonite amended tailings layer will serve as the primary rooting zone for cover vegetation on beaches. Even if root invasion were to occur, per the Hydrologic Evaluation of Landfill Performance (HELP) Model User's Manual (Reference (18)), root invasion for an excellent stand of grass affects barrier layer hydraulic conductivity by not more than a factor of 5 (one-half order of magnitude relative to hydraulic conductivity); a factor easily overcome by the application of the necessary percent of bentonite. Further, per the previously cited reference by Holl (Reference (21)), similar to the tendency for roots to spread laterally rather than to continue vertically when the roots encounter a geomembrane barrier layer, the same phenomena has been observed when roots encounter a clay barrier layer. For animal burrows in beach areas, the cumulative size of even dozens of burrows in comparison to the large beach area is assumed to be inconsequential as to impacts on the overall amount of percolation through the beach area.

8.3.4 Up Front Preparation

None required.

8.3.5 Timing and Duration of Implementation

The cover system will be implemented at mine closure and will be required to function until constituents have been depleted from the portion of the FTB that is subject to oxidation. The current model shows that it will take well beyond 200 years for the Tailings Basin to be depleted of load.

8.3.6 Other Potential Spin-Off Impacts

There could be additional particulate emissions during bentonite handling. This will be minimized because bentonite will be applied into the FTB pond These emissions will be minimized by use of granulated rather than powdered bentonite.

Another expected impact from bentonite augmentation of the tailings will be the occasional discharge of stormwater runoff from the surface of the reclaimed tailings basin. Discharges will be through a discharge channel constructed near the northeast corner of Cell 2E (Reference (5) Permit Support Drawings). This will be clean stormwater runoff that will be discharged at times when the stormwater inflow to the pond above the reclaimed basin exceeds the water holding capacity of the pond.

8.4 Engineering Control Performance Parameters

8.4.1 Description with Basis

The performance parameter for the bentonite augmented tailings is hydraulic conductivity (a.k.a. permeability). The hydraulic conductivity (k; typically stated in units of centimeters per second) of the bentonite augmented tailings in combination with the layer thickness of bentonite augmented tailings and overlying hydraulic head are the basis for computing flow through the bentonite augmented tailings layer. The expression of flow through the layer is by Darcy's Law as:

$$q=kiA \qquad \textbf{Equation 8-1}$$

where:
q = the rate of flow in units such as gallons/acre/day
k = the measured hydraulic conductivity of the bentonite amended tailings layer
i = the hydraulic head driving flow through the bentonite amended tailings layer, computed as $\Delta h/L$
Δh = the hydraulic head above the bentonite amended tailings
L = the saturated thickness of bentonite amended tailings
A = the area over which flow is being computed

By specifying and constructing the desired layer thickness of bentonite augmented tailings, by controlling the hydraulic head above the bentonite augmented tailings (via specified outlet elevation for the pond above the tailings), and by specifying and constructing the desired hydraulic conductivity of the bentonite augmented tailings (currently modeled to be 1×10^{-7} cm/sec), the desired limitations on flow through the bentonite amended tailings will be achieved.

The originally projected percent of bentonite addition to the tailings was 3-percent and this percentage will be retained in the beach areas. For the pond area the application rate (most likely in pounds per acre) will be initially estimated at the time of implementation on the basis of the percolation performance required. The confirmation of the adequacy of this application rate will be by in-laboratory permeability testing of bentonite amended tailings samples using ASTM D5084 - 10 “Standard Test Method for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter.” By this test method the hydraulic conductivity of the bentonite augmented tailings can first be determined in the laboratory and the necessary bentonite application rates can then be implemented in the field. For the pond area, a systematic construction method will be used to achieve a uniform rate and distribution of bentonite application as dictated by in-laboratory pre-application testing outcomes.

As part of initial tailings basin reclamation work, the selected construction contractor will be required to demonstrate that the means and methods selected for bentonite application to the pond bottom to yield the desired uniformity of bentonite application, accomplish this without exceeding air quality permit requirements (without generating excessive dust emissions), and yield a completed reclamation pond bottom having the specified hydraulic conductivity .

The in-laboratory hydraulic conductivity testing will be supplemented by tracking of bentonite application and tracking of construction procedures with the objective of confirming that the selected construction contractor is building the bentonite augmented pond bottom according to the project specifications.

8.4.2 Maintenance Program

The planned cover system requires very little annual maintenance to remain effective. .

8.4.3 Modeling of Engineering Controls

A 3-dimensional flow model previously established for computing seepage rate from the entire basin will continue to be utilized to model performance of the bentonite augmented pond bottom. While this model relies on Darcy’s Law (Equation 8-1) for computation of seepage, it allows for definition of as-built conditions (hydraulic conductivity, layer thickness, hydraulic head) in discrete areas of the basin and aggregates the computation of seepage from the discrete areas into a cumulative total seepage rate from the basin.

8.4.4 Impact on Compliance

Table 8-1 through Table 8-2 show the modeled measure of compliance (number of P90 results not exceeding the water quality standard / number of P90 results) for resource objectives for constituents in the surface water (tributaries) and groundwater and MPCA criteria that do not meet resource objectives with and without the enhanced cover system with the engineering control in Section 7.0 implemented.

Table 8-1 Cell 1E/2E Enhance Cover System Impact on Surface Water

Measure of Compliance								
	No Enhanced Cover				With Enhanced Cover			
Constituent	MLC-3	TC-1	UC-1	PM-13	MLC-3	TC-1	UC-1	PM-13
Al	5.0%	73.0%	79.5%	0.0%	18.5%	56.0%	79.5%	0.0%
B	100%	100%	27.5%	100%	100%	100%	27.5%	100%
Co	20.0%	20.0%	87.5%	100%	20.0%	20.0%	87.5%	100%
Cu	20.0%	20.0%	100%	20.0%	20.0%	20.0%	100%	20.0%
Ni	83.0%	100%	100%	100%	87.0%	100%	100%	100%
Pb	100%	87.0%	85.5%	100%	100%	87.0%	85.5%	100%

Table 8-2 Cell 1E/2E Enhance Cover System Impact on MPCA Criteria

Measure of Compliance								
	No Enhanced Cover				With Enhanced Cover			
Constituent	MLC-2	PM-19	PM-11	PM-13	MLC-2	PM-19	PM-11	PM-13
SO4	74.5%	100%	100%	100%	74.5%	100%	100%	100%

8.5 Anticipated Project Monitoring

The Project includes a comprehensive water quality and quantity monitoring program that will be finalized in permitting. The program includes compliance monitoring for the tributaries, PM13 and groundwater at the property boundary. See Section 5 of Reference (2) for details.

8.5.1 Special Performance Monitoring

There will be no additional performance monitoring.

8.5.2 Test Projects

There are no test projects planned.

8.5.3 Reporting and Model Update

The Project includes a comprehensive water quality and quantity reporting program that will be finalized in permitting. The program includes annual comparison of actual monitoring to modeled results for the water collected by the containment system, the tributaries and PM13. This comparison will be used to refine the model. See Section 6 of Reference (2) for details.

8.5.4 Adaptive Management and Contingency Mitigation

The Project includes a comprehensive water quality and quantity reporting program that will be finalized in permitting. The program includes adaptive management for the FTB pond water quality and ground/surface water down gradient from the FTB. See Section 6.5 and 6.6 of Reference (2) for details.

8.6 Modified Design

The annual model update may indicate a need to change the design of the Cell 1E/2E Enhanced Cover System. The system design can be modified up to the point of implementation (Section 7.3.5). The current version of this document will determine the design to be implemented.

8.6.1 Circumstances Triggering Modification

Two circumstances could trigger a design modification:

1. The development of new construction materials or techniques that would achieve the required amount of seepage prevention.

2. Demonstration by actual field monitoring of the Project and model updating that the required amount of seepage to be prevented has changed and that a modified design can achieve that performance. The required amount could change for various reasons:

    a. modeled performance of other adaptive engineering controls (Sections 7.0 and through 9.0) could change

    b. modeled constituent load from FTB could change

8.6.2 Options with Increased Performance

The design of the bentonite augmented cover system can be adjusted to increase performance if required. Increased performance could include the following items, in order of increased performance provided:

- Increased thickness of the bentonite augmented soil layer (decreases q by decreasing i in Equation 8-1).

- Increased percent of bentonite (decreases q by decreasing k in Equation 8-1).

- Combination of increased thickness and increased percent bentonite (decreases q by decreasing i and k in Equation 8-1).

8.6.3 Options with Decreased Performance

The design of the bentonite augmented cover system can be adjusted to decrease performance if required. Decreased performance could include the following items, in order of decreased performance provided:

- Decreased thickness of the bentonite augmented soil layer.
- Decreased percent of bentonite.
- Decreased thickness and decreased percent bentonite.

8.7 Financial Assurance

The cost for implementation of the cover system including periodic maintenance will be included in the Contingency Reclamation Estimate that will be the basis for financial assurance. The estimate will be updated annually based on the liability at the end of the following year. See Reference (5), Section 7.4 for details.

9.0 Flotation Tailings Basin (FTB) Groundwater Seepage Passive Treatment System

9.1 Project Feature

A Groundwater Seepage Passive Treatment System will be implemented as an engineering control during closure of the FTB. Groundwater seepage from the FTB will contain dissolved constituent load that will originate from the LTVSMC tailings used for dam construction and the NorthMet tailings placed in the facility. During operation, the FTB groundwater seepage will be collected in the containment system component of the Groundwater Seepage Management System (Section 7.0) and reused or treated and discharged in accordance with an NPDES permit.

The Enhanced Cell 1E/2E Cover System (Section 8.0) is intended to reduce the quantity of groundwater seepage in closure. In addition, the Cell 1E/2E Cover System is intended to reduce oxidation of materials in the FTB and the resulting constituent load. Implementation of the passive treatment system (described in this section) for the water that would otherwise be intercepted by the containment system will eliminate the need for the continued operation of the sumps, pumps, pipes and WWTP components of the Groundwater Seepage Management System. The Groundwater Seepage Passive Treatment System will be installed by replacing a portion of the proposed containment system alignment with a zone that will be designed as a Permeable Reactive Barrier (PRB). The remaining portions of the containment system will be left in to act as a funnel that will direct groundwater seepage through the PRB gate for final treatment.

9.2 Resource Objectives

The resource objectives are to:

- meet the applicable surface water standards (Reference (56), Tables 1-2 and 1-3) in three (Trimble Creek, Mud Lake Creek and Unnamed Creek) Embarrass River tributaries at their headwaters near the FTB. At this time, the 90th percentile probabilistic model result being below the applicable standard is assumed to meet the objectives.

- meet the applicable groundwater standards (Reference (56), Table 1-4) at the property boundary. At this time, the 90th percentile probabilistic model result being below the applicable standard is assumed to meet the objectives.

- meet MPCA criteria with regard to sulfate at the three tributary headwaters (no increase in sulfate load relative to the modeled no action condition) and PM13 (no increase in concentration relative to the modeled no action condition)

Note that this engineering control alone cannot achieve the objectives. The engineering controls described in Sections 7.0 through 8.0 are also required for constituents (B, Co, Cu, Ni, and Pb) and the engineering control described in this section is required for final passive treatment of some constituents (B, Co, Cu, Ni, and Pb) after operation of the sump, pump, pipe and WWTP components of the Groundwater Seepage Management System is discontinued.

9.3 Planned Engineering Control

9.3.1 Purpose

The purpose of the FTB Groundwater Passive Treatment System is to remove constituents (Co, Cu, Ni, Pb, SO_4, and Zn) in the water that is allowed to pass through the containment system after the operation of the sump, pump, pipe and WWTP components of the Groundwater Seepage Management System is discontinued. The removal efficiency of the Passive Treatment System for several solutes (Alkalinity, As, B, Ca, Fe, Mg, Mn, and Se) was included in Reference (56) and is not discussed further here.

The current model assumes a passive treatment system with constituent-specific percent reductions and an assumed residence time of 5 days. Actual monitoring of Project water quality parameters and annual updating of the model will determine if different percent reductions are required. Site-specific pilot testing will be used to refine and improve the passive treatment system design that will achieve the required percent reductions (Section 9.5.2).

9.3.2 Design

The proposed passive treatment system for the FTB groundwater seepage is a PRB. Within a PRB, sulfate is transformed in the subsurface to sulfide by sulfate reducing bacteria (Reference (30)). This process occurs in anaerobic environments and has the benefit of precipitating dissolved metals as insoluble metal sulfides. This process is enhanced *in situ* by the addition of a degradable organic substrate (Reference (31)). Other materials that can be added to supplement the process include nutrients (nitrogen and phosphorous) and zero valent iron (ZVI). The ZVI provides additional inorganic reduction within a PRB that helps to stabilize conditions that are favorable for sulfate reducing bacteria (SRB) (Reference (32)). The ZVI also provides dissolved iron to the solution that will help to bind the excess sulfide generated during the process. The portion of the PRB that contains the organic substrate and supplemental material is the treatment unit.

The basic design factors for a PRB include:

- Adequate hydraulic retention time in the treatment unit for the development of a stable microbial population. This is normally on the order of 5 days in colder climates (Reference (33)).

- A design configuration that promotes an even distribution of flow through the treatment unit. This is accomplished using gravel media and drain tile to distribute the flow throughout the treatment unit (Reference (34)).

- Placement of drain-field piping or other access points to allow the replacement/replenishment of organic substrate and supplemental material in the treatment unit, as necessary.

An effective PRB requires an organic substrate and an adequately matched microbial community that will maintain anoxic conditions and support SRB. The submerged sediments of most natural wetlands in Minnesota contain all of the components necessary to promote sulfate reduction and metal precipitation; however, they may not have the appropriate hydraulic configuration. To provide the proper hydraulic configuration, PRB design will include delivery and collection systems on the front and back side of the treatment unit to aid in the distribution of the flow. This will consist of gravel filled trenches with distribution piping. Within the PRB treatment unit, native soils will be supplemented with degradable organic matter to promote biological activity and coarse materials (sand and gravel) to promote even distribution of the flow within the PRB. Additional basic PRB design guidance is available from numerous sources, including the ITRC (Reference (35)).

For the FTB Groundwater Passive Treatment System, the total flow is expected to be approximately 1,200 gpm for the combined flows modeled at the north, northwest, west, and south toes. The required area for a PRB is approximately 3 acres, using an annual average flow of 1,200 gpm, a hydraulic retention time of 5 days, an average working treatment depth of approximately 30 feet, and a field porosity of 30 percent as design parameters. A conceptual location and cross section for a PRB is shown on Figure 9-1 and Figure 9-2. The conceptual plan includes replacing several portions of the containment and collection system with PRB units installed in the gates. A total of seven gates are shown on the conceptual figure, with the remaining portion of the containment system left in place to funnel the flow to the PRB gates.

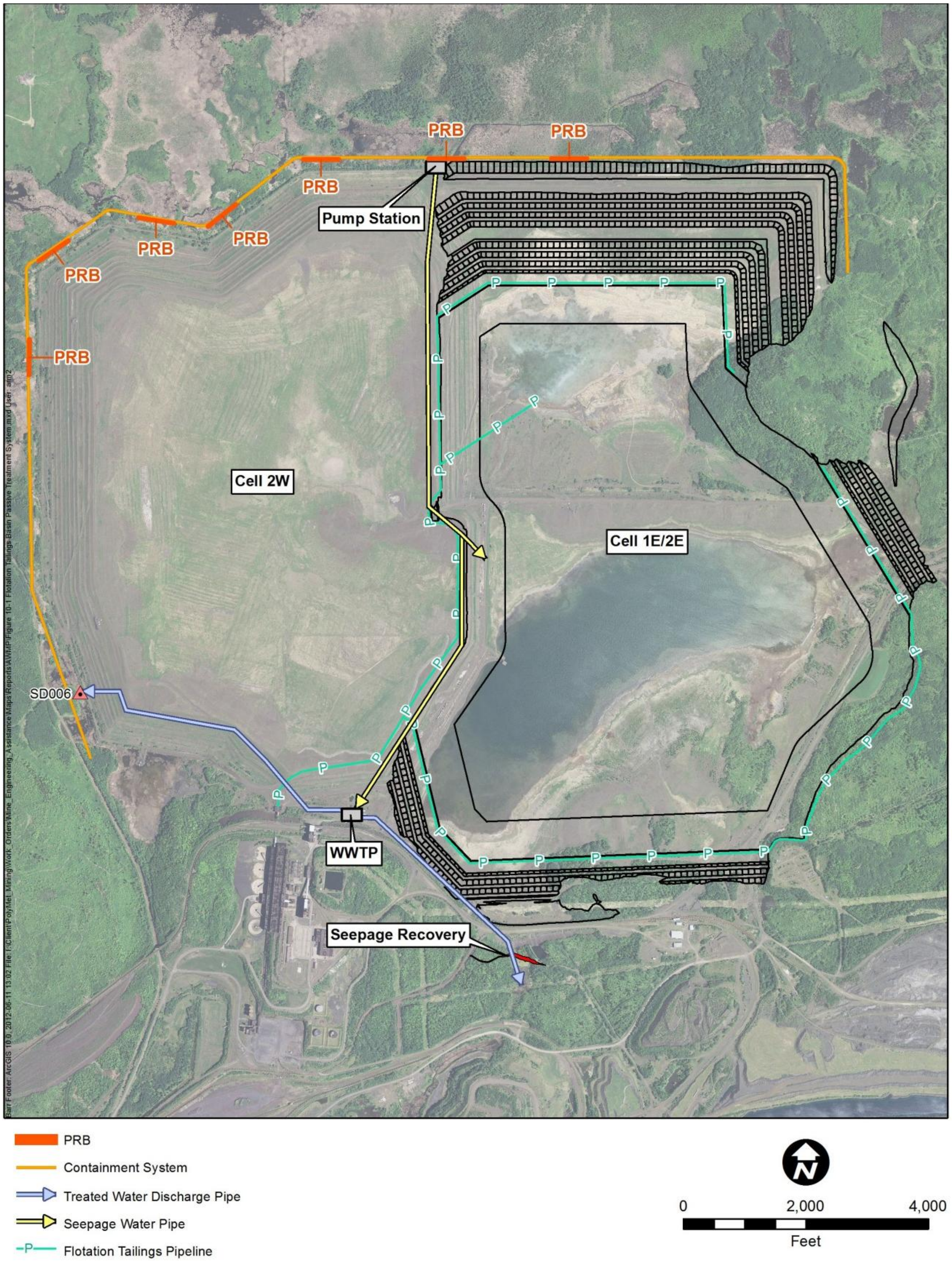

Figure 9-1 Conceptual Plan View Flotation Tailings Basin Groundwater Seepage Passive Treatment System

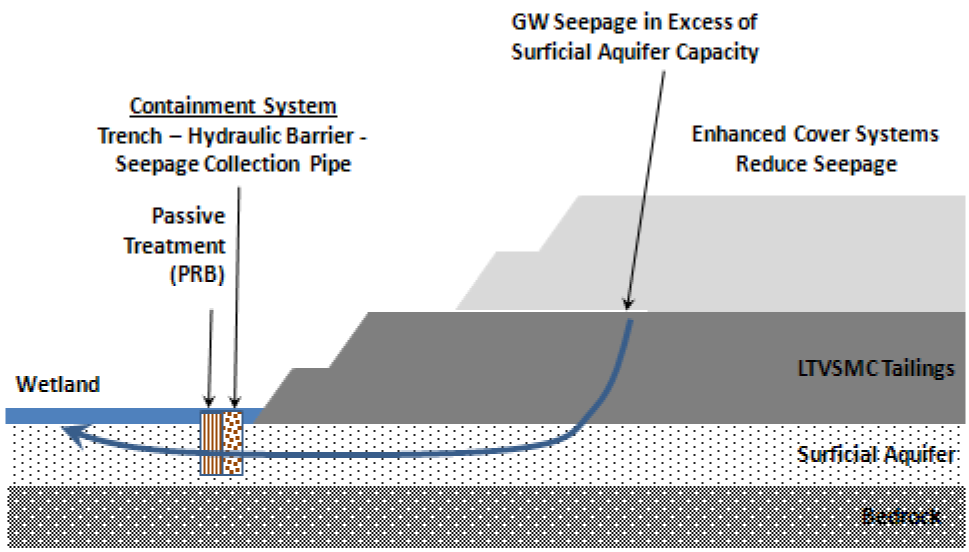

Figure 9-2 Simple Cross Section - PRB

9.3.3 Degree of Use in Industry

The development and use of PRBs to treat groundwater flows was initiated in the 1990s (Reference (35)) and recently has seen extensive application to sites with groundwater impacts, including the refinement of the techniques needed to custom design PRB systems. This technology was developed as method to enhance natural processes within the groundwater flow regime that contribute to the transformation of organic compounds or the transformation of dissolved inorganic compounds into insoluble products (Reference (35)). Most PRB systems have been installed in the subsurface for the treatment of groundwater. This configuration also facilitates year-round operation and relatively stable temperatures. Over 200 full-scale PRBs have been installed to treat groundwater at a variety of sites, and a recent guidance document on PRB systems provides 13 specific case histories of PRB implementation (Reference (35)). The development of PRBs specific to mine water drainage is an important component of PRB applications and also dates to work that originated in the 1990s ((Reference (31)) as well as earlier work on passive treatment of acid mine drainage in a variety of configurations that all have similar operating characteristics (Reference (36)).

9.3.4 Up Front Preparation

The plan for the FTB Groundwater Seepage Management System must account for installation of the passive treatment system in closure. This is accomplished as described in Section 7.0.

9.3.5 Timing and Duration of Implementation

The passive treatment system will be implemented after the FTB hydrology stabilizes and will be required to function until constituents have been depleted from the portion of the FTB that is subject to oxidation. The current model shows that it will take well beyond 200 years for the Tailings Basin to be depleted of load.

The passive treatment system must be functional before operation of the WWTP is discontinued. Assuming that a two year construction period and biological acclimation is required, construction must start at the beginning of the construction season three years before operation of the WWTP is discontinued as determined by the 10^{th} percentile lowest Mine Year in the current Project water quality model.

When the operation of the Groundwater Seepage Management System described in Section 7 is discontinued, the resource objectives will be achieved by the FTB Groundwater Seepage Passive Treatment System. The timing of this change will be determined by post closure monitoring.

9.3.6 Other Potential Spin-Off Impacts

The proposed footprint for the FTB Groundwater Passive Treatment System is shown on Figure 9-1. Wetlands along this alignment will be impacted by the installation of the containment system component of the Groundwater Seepage Management System. No additional wetland impacts are anticipated for the conversion of a portion of the collection system to a PRB.

The PRB will operate by gravity and is not expected to have any impacts associated with air quality or geotechnical design. The used organic substrate and supplemental material removed during periodic replacement will be disposed.

9.4 Engineering Control Performance Parameters

9.4.1 Description with Basis

9.4.1.1 Percent Reduction

The primary performance parameter associated with passive treatment systems is the Percent Reduction of the constituent being treated

Influent Concentration x (1 – Percent Reduction) = Effluent Concentration **Equation 9-1**

Passive water treatment systems are capable of removing multiple constituents with similar characteristics. For example, all metals that form insoluble precipitates with sulfide can be effectively removed using the same PRB provided the proper conditions for sulfate reduction (pH, redox potential, and temperature) are established and provided sufficient sulfate is available for reduction. Both of these conditions will exist within a PRB for the treatment of the FTB Groundwater. Many of these parameters are controlled in passive water treatment systems based on the selection and placement of the solid-phase, flow-through media.

Of particular interest to this project, a barrier that was installed in northern Quebec at the Cadillac Molybdenum Mine site and was operated successfully through winter conditions as reported by Kuyucak, et al (Reference (37)). In this system, a solid-phase organic media was used to generate favorable conditions for sulfate reducing bacteria. The treatment system reduced copper concentrations from 300 ug/L to an average effluent concentration of 8 ug/L. Nickel and zinc reductions of an order of magnitude or more were also observed. Sulfate reduction rates up to 75 percent with an influent value of 810 mg/L being reduced to 210 mg/L even during winter conditions were also observed. The successful winter operation of a passive system in a cold climate confirms that this engineering control is capable of significantly reducing the load of metals in the water from the FTB Groundwater Containment System before it enters Embarrass River system.

Based on the work of Kuyucak, et al. (Reference (37)), and others, the modeled percent reductions for metals in the PRB for Category 1 waste rock stockpile drainage are summarized in Table 9-2.

Table 9-1 Model Treatment Performance: FTB Groundwater Seepage Passive Treatment System

	Percent Reduction	Basis
Cobalt	90	Laboratory study (Reference (39)) and geochemistry (Reference (38))
Copper	90	Field analog (Reference (37))
Nickel	90	Field analog (Reference (37))
Zinc	90	Field analog (Reference (37))
Lead	90	Field analog (Reference**Invalid source specified.**)
Sulfate	50	Field analog (Reference (37))

9.4.1.2 Media Useful Life

A secondary performance parameter associated with passive treatment systems is the media useful life. Organic substrate can be replenished naturally from plant growth (i.e., in a wetland), replacement of the solid phase media, or periodic injection of soluble organic materials. The design hydraulic loading rate for a PRB system is 1,200 gpm with an annual average sulfate mass flux of 320 mg/L. Using these values, the organic media requirement can be estimated based on the stoichiometric conversion of sulfate, which requires approximately 2 moles of organic carbon per mole of sulfate. Based on this value, using a conservative carbon production rate of 50 moles/m^2/yr for wetland systems (Reference (40)) would require a wetland area of approximately 38 acres to provide enough carbon for the system to be self-sustaining. Thus, the system could be made larger than the 3 acre footprint to eliminate maintenance activities or the organic matter produced locally on 38 acres of land could be composted and used as substrate addition. The organic substrate within a 3 acre by 30 foot deep treatment volume would be expected to last approximately 60 years, assuming 50 percent of the volume is organic matter and 20 percent of the organic matter is carbon.

Alternatively, replenishing a PRB system via injection of supplemental substrate such as ethanol could be considered. The annual mass of degradable organic matter consumed would need to need to contain approximately 185,000 Kg of carbon. Using a value of 1.55 Kg C per gallon of ethanol, this equates to approximately 120,000 gallons annually that could be applied through an infiltration gallery, similar to a conventional septic system drain-field.

9.4.1.3 Model Parameters

Table 9-2 summarizes model parameters that will represent the FTB Groundwater Seepage Containment Passive Treatment System. The analogs used to establish percent reductions are based on field-scale operations because, when available, they present a better indicator of full-scale performance than bench-testing.

Table 9-2 Model PRB Treatment Performance: FTB Groundwater Seepage Containment Passive Treatment System

	Percent Reduction	Basis
Cobalt	90	Laboratory study (Reference (32)) and geochemistry (Reference (31))
Copper	90	Field analog (Reference (37))
Nickel	90	Field analog (Reference (37))
Zinc	90	Field analog (Reference (37))
Lead	75	TBD
Sulfate	50	Field analog (Reference (37))

9.4.2 Maintenance Program

The planned passive treatment system may require periodic maintenance to remain effective. The periodic maintenance would consist of replacement of media as determined by media useful life or periodic application of liquid substrate.

The useful life of the media is 60 years. The full depletion of constituents from the FTB is expected to be greater than 2000 years. Given the extended time period predicted for depletion and the uncertainty inherent in the model around this prediction, the actual number of media replacements will need to be determined during operations using actual monitoring data. However, it is currently assumed that at lease 34 replacements will be necessary.

9.4.3 Modeling of Engineering Controls

The PRB passive treatment system for the FTB Groundwater Passive Treatment System will be incorporated into the Plant Site water model. In general, this element will have the following characteristics:

- The design discharge volume will be the annual average flow to the FTB Groundwater Containment System.
- The PRB will be incorporated into the GoldSim model as a set of percent reductions for the concentrations of a variety of constituents as listed in Table 9-2.
- No other parameters will change in the modeling.
- The performance of the PRB will not change over time.

9.4.4 Impact on Compliance

Table 9-3 through Table 9-4 show the modeled measure of compliance (number of P90 results not exceeding the water quality standard / number of P90 results) for resource objectives for constituents in the surface water (tributaries) and groundwater and MPCA criteria that do not meet resource objectives with and without the passive treatment system with the engineering controls in Sections 7.0 through 8.0 implemented.

As shown in Table 9-3, lead is still showing exceedances in the tributaries immediately downstream of the Tailings Basin. The mitigations listed up to this point have completely cut off Tailings Basin seepage from the headwaters of the tributaries through 20 years after closure (year 40). During this time, the headwater locations of the tributaries are solely receiving surface runoff from unimpacted areas and this is the time when lead occasionally exceeds the hardness based standard because of the very low hardness assumed for the runoff. Once seepage from the Tailings Basin is no longer captured lead no longer is modeled to exceed the standard.

Table 9-3 FTB Passive Treatment System Impact on Surface Water

Measure of Compliance								
	No FTB Passive Treatment				With FTB Passive Treatment			
Constituent	MLC-3	TC-1	UC-1	PM-13	MLC-3	TC-1	UC-1	PM-13
B	100%	100%	27.5%	100%	100%	100%	100%	100%
Co	20.0%	20.0%	87.5%	100%	100%	100%	100%	100%
Cu	20.0%	20.0%	100%	20.0%	100%	100%	100%	100%
Ni	87.0%	100%	100%	100%	100%	100%	100%	100%
Pb	100%	87.0%	85.5%	100%	100%	87.0%	85.5%	100%

Table 9-4 FTB Passive Treatment System Impact on MPCA Criteria

Measure of Compliance								
	No FTB Passive Treatment				With FTB Passive Treatment			
Constituent	MLC-2	PM-19	PM-11	PM-13	MLC-2	PM-19	PM-11	PM-13
SO4	74.5%	100%	100%	100%	100%	100%	100%	100%

9.5 Anticipated Project Monitoring

The Project includes a comprehensive water quality and quantity monitoring program that will be finalized in permitting. The program includes compliance monitoring for the tributaries, PM13 and groundwater at the property boundary. See Section 5 of Reference (2) for details.

9.5.1 Special Performance Monitoring

No Special Performance Monitoring is planned.

9.5.2 Test Projects

A test project will be developed [detailed design in permitting and included in this document] to evaluate the effectiveness of the planned passive treatment system. A pilot scale passive treatment system of the planned design will be constructed near the WWTP and use a slip stream of the water from the containment system as inflow.

9.5.3 Reporting and Model Update

The Project includes a comprehensive water quality and quantity reporting program that will be finalized in permitting. The program includes annual comparison of actual monitoring to modeled results for the tributaries, PM13 and groundwater at the property boundary as well as water from the containment system and FTB pond. This comparison and results from Test Projects above will be used to refine the model. See Section 6 of Reference (2) for details.

9.5.4 Adaptive Management and Contingency Mitigation

The Project includes a comprehensive water quality and quantity reporting program that will be finalized in permitting. The program includes adaptive management for the FTB pond water quality and ground/surface water down gradient from the FTB. See Section 6.5 and 6.6 of Reference (2) for details.

9.6 Modified Design

The annual model update may indicate a need to change the design of the passive treatment system. The passive treatment system design can be modified up to the point of implementation (Section 9.3.5). The current version of this document will determine the design to be implemented.

9.6.1 Circumstances Triggering Modification

Two circumstances could trigger a design modification:

1. Demonstration by actual field testing or analog sites that a modified passive treatment system design will achieve the required percent reduction.

2. Demonstration by actual field monitoring of the Project and model updating that the required percent reduction has changed and that a modified design can achieve that percent. The required percent reduction could change for various reasons:

    a. modeled performance of other adaptive engineering controls (Sections 7.0 through 8.0) could change

    b. modeled constituent load from the FTB could change

9.6.2 Options with Increased Performance

The design of the passive treatment system can be adjusted to increase performance if required. Increased performance could include the following items, in order of increased performance provided:

- Longer retention times would allow more time for the flow to interact with the sulfate reducing bacteria within the wetland.

- Different media that could improve the rate of degradation or prolong the overall treatment - for example APTsorb material (Section 6) could be mixed into the PRB substrate matrix to sorb metals until they can react with excess sulfide within the treatment compartment.

9.6.3 Options with Decreased Performance

The design of the passive treatment system can be adjusted to decrease performance if required. Decreased performance could include the following items, in order of decreased performance provided:

- Partial or complete bypass: The PRB in some of the gates could be replaced with a permeable material

- Alternative media: different media with a longer operating life, but potentially less affinity for metal sorption could be used to decrease the performance of the system, while also decreasing the potential replacement frequency.

- Shorter retention time would extend the useful life of the solid phase organic substrate while reducing the percent reductions obtained from the treatment system. Shorter retention time.

- Different media.

9.7 Financial Assurance

The cost for implementation of the passive treatment system including test project (Section 9.5.2), periodic maintenance and media replacement or replenishment will be included in the Contingency Reclamation Estimate that will be the basis for financial assurance. The estimate will be updated annually based on the liability at the end of the following year. See Reference (2), Section 7.4 for details.

Revision History

Date	Version	Description
6/11/12	1	Initial release
7/10/12	2	Responses to comments on Version 1 • Section 5 - eliminated expanded WWTF and added antimony and lead treatment • Section 6 – added lead treatment • Section 8 – moved enhanced bentonite for beach to contingency mitigation • Section 9 – moved to contingency mitigation section

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